CHAPTER 22

MEASUREMENT INSTRUMENTATION AND METHODS

INTRODUCTION

This chapter will discuss the various methods, components and criteria that might reasonably be expected to be found in typical utility piping systems that are used to provide a variety of commonly used measurements and metering methods for liquids and gases and level measurements for fluids and solids.

For most systems described in this chapter, different forms of measurement are very important for maintenance and control purposes. These systems are not generally as demanding in terms of extreme accuracy except where required by healthcare, laboratory and other specific reasons. Health care facilities depend on many forms of measurement to assure correct flow, continued reliability and performance of life safety equipment and piping distribution networks; and for laboratories, correct pressures and flow are critical for the correct performance of various equipment and also in calibrating and analysis types of instruments and equipment.

GENERAL

The subject of measurement is important to many aspects of facility piping systems. The information necessary to maintain proper system conditions, confirm design parameters and to obtain actual operating conditions when repair is necessary can only be obtained from various instruments installed in the distribution system or at the equipment. Subjects to be discussed in this chapter are:

1. Flow measurement

2. Level measurement

3. Temperature measurement

4. Pressure measurement

5. pH measurement

6. Metering pumps

7. Measuring flow in open channels

8. Miscellaneous
Sight glass
Thermowells
Space for piled materials

CODES AND STANDARDS

1. ISA Specification S-20, Instrument Data Sheet
2. British Standard BS 7405, Selection Standard for Meters
3. AWWA 700 series, standards for water meters
4. Various standards for almost all of the devices discussed too numerous to mention

DEFINITIONS

The following are definitions of terms used in the following discussions.

Reynolds Number

The performance of flowmeters is influenced by a dimensionless unit called the Reynolds number. It is defined as the ratio of the liquid's inertial forces to its drag forces. The equation is:

$$R = \frac{3160 \times Q \times G}{D \times \mu} \tag{22.1}$$

where R = Reynolds number
Q = measured liquid's flow rate, gpm
G = measured liquid's specific gravity
D = pipe inside diameter, inches
μ = measured liquid's viscosity, centipoise

The flow rate and the specific gravity are inertia forces, and the pipe diameter and viscosity are drag forces. The specific gravity and pipe diameter remain constant for most applications.

R values below 2000 are considered laminar flow and R values above 3000 are considered turbulent flow. Values between 2000 and 3000 is a transition zone where flow could be either laminar or turbulent and is based on piping and installation conditions. Most applications involve turbulent flow.

Viscosity

Absolute or dynamic viscosity for a liquid is defined as the ratio of sheer stress to the sheer rate. If a cubic volume of liquid were isolated, the sheer stress is the relative force between the top and bottom divided by the length between them. The units of sheer stress are given as dines per square centimeter (dyne sec/cm2) or centipoise. More simply stated, it is a measure of the internal friction that exists as the liquid flows. The more it resists the tendency to flow, the higher the viscosity.

Kinematic viscosity is the dynamic viscosity divided by the density of the liquid. The units of kinematic viscosity are given as centistokes. The conversion from dynamic viscosity to kinematic viscosity is calculated by dividing the dynamic viscosity by the fluid density in grams per cm^2.

Care must be taken when comparing manufacturers' specifications for flowmeter capacity.

NEWTONIAN FLUIDS

A Newtonian fluid is one in which the viscosity does not depend on the sheer rate and which exhibits sheer stress proportional to sheer rates, such as water and mineral oil. No matter what sheer rate is applied, the viscosity stays the same. A non-Newtonian fluid will change viscosity as the liquid is sheared at a greater rate.

Another classification of non-Newtonian fluid is called a *plastic fluid.* This type will behave as a solid until a critical sheer rate is achieved (called the yield value), at which time the fluid will start to flow.

Water is a Newtonian fluid. Paint is a non-Newtonian fluid because it will decrease its viscosity with an increasing flow rate. Ketchup is an example of a plastic fluid since it is difficult to pour until an appropriate shear rate is reached. Viscosity changes will cause misregistration in turbine and positive displacement flowmeters meters and other level measuring methods.

SENSORS

A sensor is a device that measures some condition—temperature, pressure or flow—and provides a signal to an instrument package that converts that signal to a useful indication of the condition being measured.

HYDRAULIC RADIUS

The hydraulic radius, a term used for open channel flow, is the ratio of cross section area to the wetted perimeter of a channel. It is not a radius in the geometrical sense. It relates two important parameters that influence the movement of water in a channel. The first is the cross sectional area of the water, which is directly proportional to the volume of water (flow rate) carried in the channel. The second is the length of the solid surface of the channel (wetted perimeter), which resists the movement of the water.

The cross sectional area is defined as the actual area of water flowing in the channel. The wetted perimeter is the linear surface contacted by the flowing water excluding the surface of the water.

FLOW MEASUREMENT

Flow is defined as fluid volume per unit of time.

Flowrate of fluids is one of the most widely measured variables in industry. The measurement is made by means of some type of flowmeter (meter). These discussions will concern the terms, principles of operation, advantages and limitations of the most commonly used meter types for facility type applications.

FLOWMETER CLASSIFICATION

Flowmeters are often divided into two large, major categories: those that measure quantity or those that measure flow rate. The meters will be divided into additional sub-categories that further define their method of operation. A simple classification of the various flowmeters will help visualize the operating principles of the various meter types.

Displacement meters, often referred to as positive displacement meters, measure or count successive and discreet quantities of fluids. They divide the flow stream into discrete units of volume and capture these volume units in a measuring chamber. The meter then measures these captured volume units passing through the meter. Positive displacement meters include piston, oval gear, notating disk and rotary vane types.

Velocity type meters measure the rate of flow and operate linearly. There is no square root relationship as with differential meters, so their rangeability is greater. In these meters, the measuring element is placed in the flowing stream and either converts potential energy into kinetic energy (where energy is lost due to pressure drop) or extracts energy in the form of work done to the object in the flow path, such as a turbine or rotor. Examples of velocity meters that convert energy are the differential pressure, positive displacement, turbine and vortex meters. Velocity meters that add energy require adding some form of energy to the meter in order to obtain a flow measurement. The effects of either the fluid on the added energy or the added energy on the fluid are observed and related to the actual flowrate. Examples of the of additive energy meters are magnetic flowmeters, sonic meters, ultrasonic Doppler type, Coriolis and thermal mass meters.

Differential pressure flowmeters, or head-type flowmeters, are among the oldest and most common meters. They operate on Bernoulli's principle of energy conservation, where the sum of static energy (pressure head), kinetic energy (velocity head) and potential energy (elevation head) is constant for flow across a restriction in a pipe. The derived basic flow formula states that the flowrate is proportional to the square root of the differential pressure developed across the restriction. Examples of differential meters are orifice plates, venturi tubes, pitot tubes, flow nozzles and variable flow meters.

Mass flow meters measure volumetric rate of flow and include Coriolis and thermal types. Because the mass does not change, this type of meter is linear with no adjustment required for variations in liquid properties.

Electronic flowmeters that do not require intrusion into the flow stream.

Open channel flowmeters include weirs and flumes.

PRINCIPLES OF FLOWMETER OPERATION

Variable Area Flowmeters

The variable area flowmeter, sometimes called a rotometer, measures volumetric rate of flow. This type is mainly used for gases and is one of the oldest technologies available. It is constructed of a tapered tube, usually of glass or plastic, and a free moving float. Fluid moving through the meter causes a pressure drop across the float producing an upward force that causes the float to move up and down the tube. As this occurs, the cross sectional area between the tube walls and the float varies, giving the meter its name. The displacement of the float is proportional to the volume of fluid flowing through the device. The accuracy of this type of meter is 2 to 4 percent full scale.

Two types of meter are available: direct reading and correlated. The direct reading meter has a scale numbered in the flowrate and units desired and allows the actual flow to be read directly off the scale. The correlated meter is divided into a unitless scale that requires a separate data sheet to allow conversion of the scale into units of flow.

Another variable is the direction of flow of fluid through the meter; this can be through the tube from top to bottom or straight through the meter only at the bottom. In the top to bottom type, illustrated in Fig. 22.1, flow is directed from the bottom to the top. The float is displaced by the volume of the fluid. In the straight through type, illustrated in Fig. 22.2, the float moves up and down in proportion to the flow rate and the area of the tapered tube.

The variable area flowmeter is well suited for measuring liquid or gas flow for plants, laboratories and health care facilities and for purging of gas lines. The effect of pressure and temperature variations for gases will cause a deviation from the actual indicated flowrate depending on the set point of the meter. If accurate flow rate is an important consideration, this deviation should be obtained from the manufacturer.

Thermal Mass Flowmeters

A mass flowmeter measures volumetric rate of flow and is an often used gas measurement technology. A typical thermal mass flowmeter is illustrated in Fig. 22.3.

The inlet gas stream enters the meter chamber and is immediately split into two separate paths. Most of the gas will pass through the bypass tube but a fraction of the gas will enter the sensor tube, which is isolated from the main fluid flow path. The sensor tube contains two temperature coils that introduce heat into the sensor tube. When gas passes through the sensor tube, it carries heat from the upstream coil to the downstream coil. The difference in temperature creates a proportional resistance change in the sensor windings in the sensor tube. The resistance change created by the temperature difference is amplified and calibrated to give a digital readout of the actual flow. The accuracy of this type of meter is ± 1.5 to 2 percent fullscale.

Another type of mass flowmeter is a single probe device often used for lower flows that occur in facility and laboratory type operations. This single probe meter uses two elements in the one probe: a reference RTD and active RTD. As the gas flows past the sensor, the flow causes a difference in temperature between the two sensor parts that is measured and converted into flow indication.

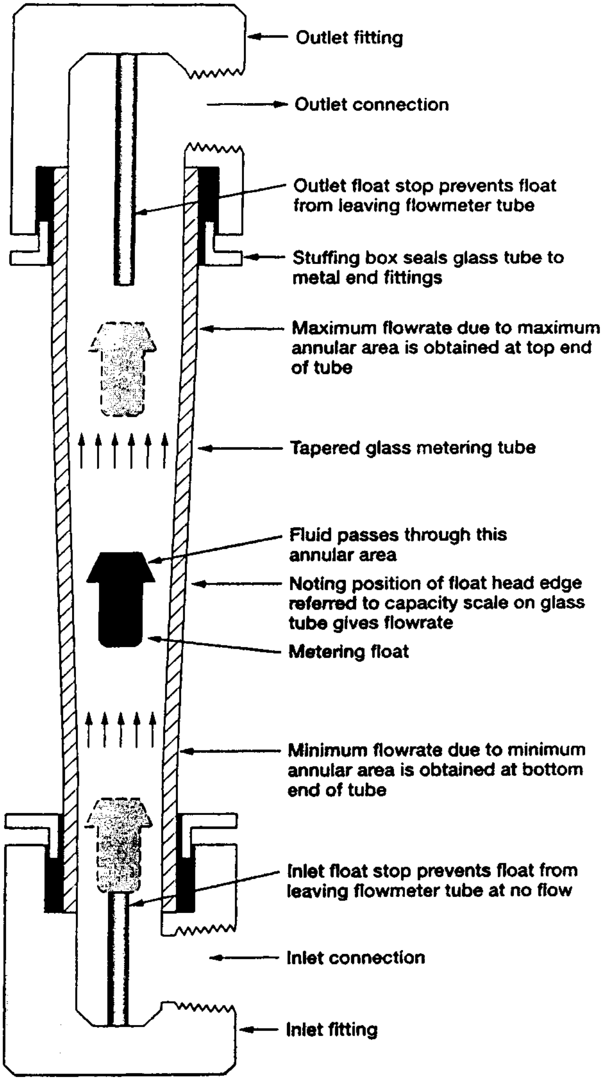


FIGURE 22.1 Typical top to bottom flowmeter.

The greatest advantage of the mass flowmeter is the ability to lower any variations of flow due to temperature and pressure changes to a point where they can be considered almost negligible. Typical differential values of flow for temperature are 0.10 percent full flow per degree Celsius and 0.02 percent per psi. Where the measure of costly gases is required, the mass flowmeter is a more appropriate choice because of its greater accuracy.

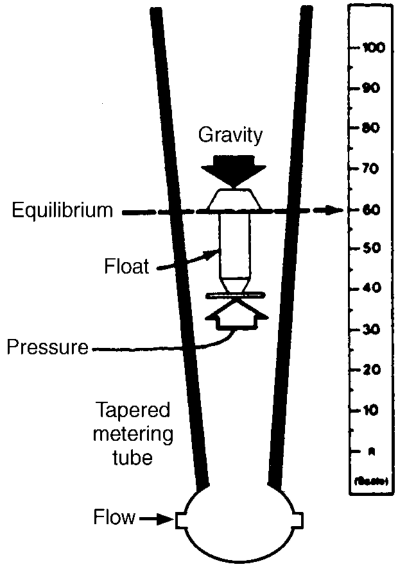


FIGURE 22.2 Typical straight through flowmeter.

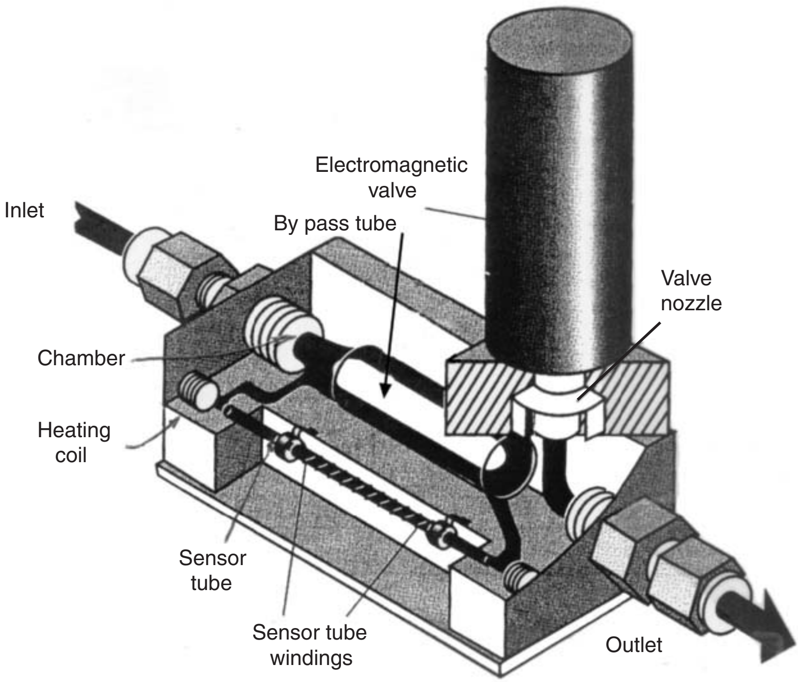


FIGURE 22.3 Typical mass flowmeter.

Coriolis Effect Flowmeters

A Coriolis effect meter is a velocity-type meter that directly measures mass rate of flow. It is unaffected by changes in liquid properties such as pressure, temperature, viscosity and density. This type of meter is used where accuracy, which approaches 0.05 percent of full flow, is required and where the previously mentioned parameters are useful. It is used to measure both liquids & gases where only the total volume of liquid is desired rather than the flowrate.

The meter operates on the Coriolis effect, which is an inertial force discovered by the 19th century mathematician Gustave-Gaspard Coriolis. The basic operation concerns one or more vibrating tubes through which the liquid to be measured flows. Tubes are manufactured in various forms, including straight line, ‘‘U’’, S and Z shaped and helix or coiled configurations.

Simply stated, the tube through which the fluid to be measured flows is vibrated. As the fluid flows through the tube, it accelerates and opposes the vibrating motion and imparts a twist to the tube. The amount of twist is proportional to the fluid mass flowrate flowing through the tube. The amount of twist is measured and a direct reading is produced. This flowmeter is best for clear fluids installed in piping 6″ and smaller.

One often used type of unit consists of a ‘‘U’’ shaped tube through which the liquid flows, illustrated in Fig. 22.4a. The tube is vibrated by an electro-magnetic device located at its bend, similar to that of a tuning fork. The oscillation occurs even when there is no flow. As the liquid flows through the tube, it is forced to take on the vertical movement of the vibrating tube. A straight line tube is illustrated in Fig 22.4b, and a helix arrangement is illustrated in Fig 22.4c.

Orifice Meter

An orifice is a differential-pressure type meter that measures flow rate. It consists of a flat plate with a specific size hole or opening and has no moving parts. In

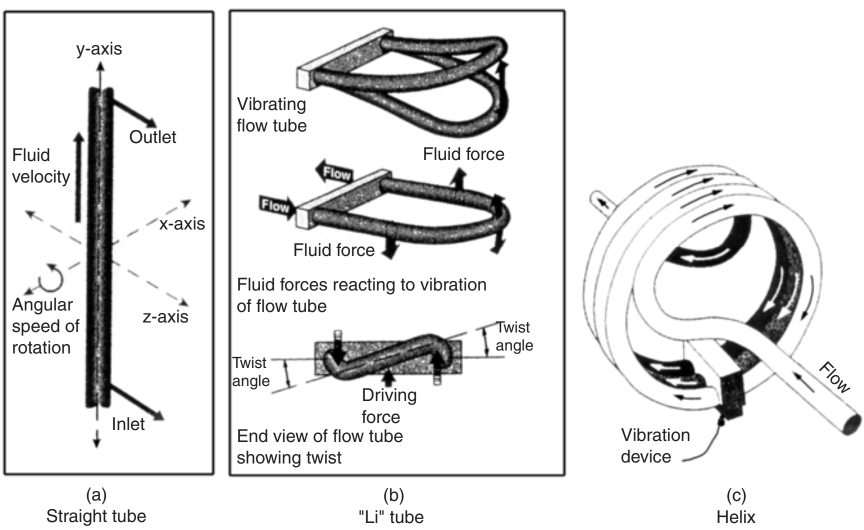


FIGURE 22.4 Typical Coriolis flowmeter.

practice, the orifice plate is often installed between two flanges downstream from a section of straight and uniform run of pipe of approximately 20 pipe diameters. Straightening vanes installed in the downstream piping will shorten the length of straight pipe runs. A typical orifice meter installation is illustrated in Fig. 22.5.

The position of the hole in the plate can be concentric, eccentric, or segmental type. The cross section shape of the hole can be either square edged or conical. These holes are illustrated in Fig 22.6.

The basic operation requires a primary and secondary element. The primary element, or orifice, constricts the flow of liquid. This produces a difference of

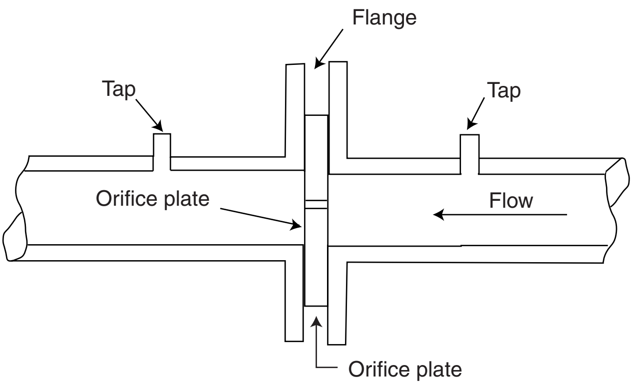


FIGURE 22.5 Typical orifice meter installation.

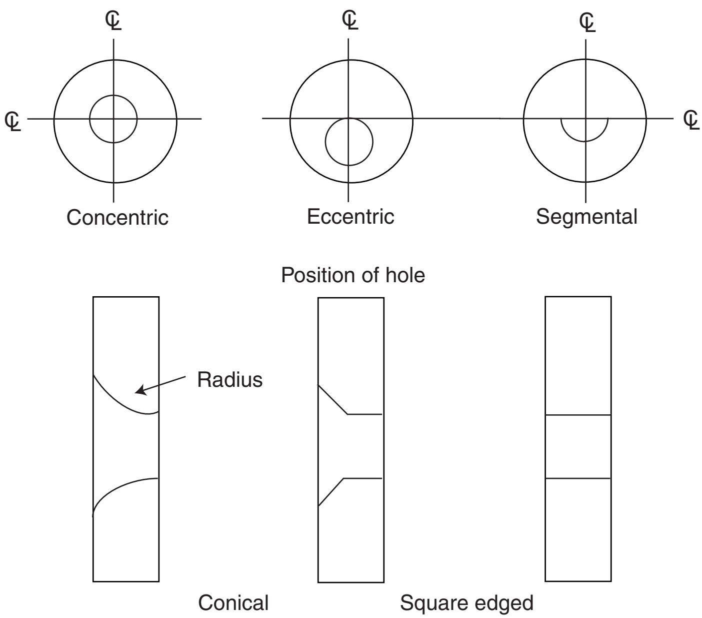


FIGURE 22.6 Hole shape.

pressure on both sides of the orifice plate. The secondary element measures the differential pressure and provides the signal or readout that is converted to the actual flowrate value. The instrumentation package is installed into taps on both sides of the plate that is used to measure the different pressures and provide the readout. The most common position of these taps are 2 pipe diameters upstream and 8 pipe diameters downstream of the flange containing the orifice plate.

The formula for flow rate is derived from the area of the pipe and the velocity of the liquid. A simplified formula for determining flow rate is:

$$W = 275 \times d^2 \times \sqrt{\frac{hp}{1 - b^4}} \tag{22.2}$$

where W = flow rate, lbs per hour
d = orifice diameter, inches
h = differential pressure, inches water
p = density of fluid, lbs per cu. ft
b = ratio of orifice diameter to pipe diameter

Venturi Tubes

A venturi tube meter, often referred to as a tube meter, is a differential-pressure-type meter that measures flow rate. The meter is a manufactured unit consisting of a tapered converging section, a throat and a tapered diverging section intended to be installed inline. It has no moving parts. The angle of the entrance section is usually between 20 to 25 degrees. The angle of the diverging section is usually between 5 to 15 degrees. This meter is used to measure large flows with a low pressure loss. A typical venturi meter is illustrated in Fig. 22.7.

The liquid to be measured enters the converging section and increases in velocity as it enters the throat. As this occurs, part of the static head of the liquid is converted into velocity head in the throat. This causes a pressure differential between the converging section and the throat. The difference in head is proportional to the flow. The instrument package converts the difference in head to flow rate. This is given in the following formula:

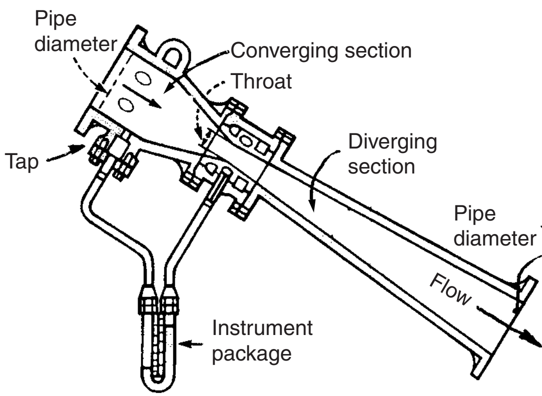


FIGURE 22.7 Typical venturi meter.

$$Q = C \times A \times k \sqrt{\Delta H} \tag{22.3}$$

where Q = volumetric flow rate, cfs
C = discharge coefficient (0.98 for this type meter)
A = area of pipe, square feet
H = differential head, ft
k = is given as:

$$k = \frac{2g}{1 - \frac{d2^4}{d1}} \tag{22.4}$$

where $d1$ = upstream pipe diameter, ft
$d2$ = venturi throat diameter, ft
g = gravity constant (32 ft/sec/sec

Flow Tube Meter

A flow tube meter is similar to the venturi tube except for the lack of an entrance throat. The throat is tapered and the exit portion is smooth and elongated.

Pitot Tube Meter

A pitot tube meter is a differential-pressure-type meter that measures flow rate. It has no moving parts. The original multi-port averaging device was invented by Henri Pitot. This meter type is suitable for measurement of liquids, steam and gases.

The pitot tube is an assembly of two isolated tubes, or chambers, within a single probe. Multiple sensing holes are drilled into each chamber to sample both the high velocity at the center of the probe and the lower pressure at the outer chamber. The probe is positioned in the fluid stream so that the ports in one chamber are facing upstream and the others are facing downstream. The inner chamber is called the impact tube and the outer one is called the static tube.

The probe's obstruction to flow creates an impact pressure on the upstream-facing tube that is continuously sampled and averaged, and the downstream facing holes sample and average the static pressure. A typical pitot tube meter assembly is illustrated in Fig. 22.8. A schematic detail of the two often used probe arrangements, straight and curved, is illustrated in Fig. 22.9.

The pitot tube assembly is installed into the flow stream by means of a pipe tap or welded coupling on the pipe. In operation, the liquid to be measured flows past the pitot tube assembly, which senses two pressures simultaneously, impact and static. An instrument package senses the differences between the static and impact pressures and converts it into flow rate.

The basic equation for determination of flow is:

$$Q = A\ K \sqrt{\frac{2g\ DP}{DE}} \tag{22.5}$$

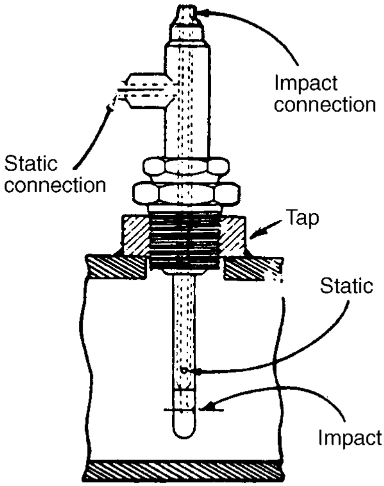


FIGURE 22.8 Typical pitot tube.

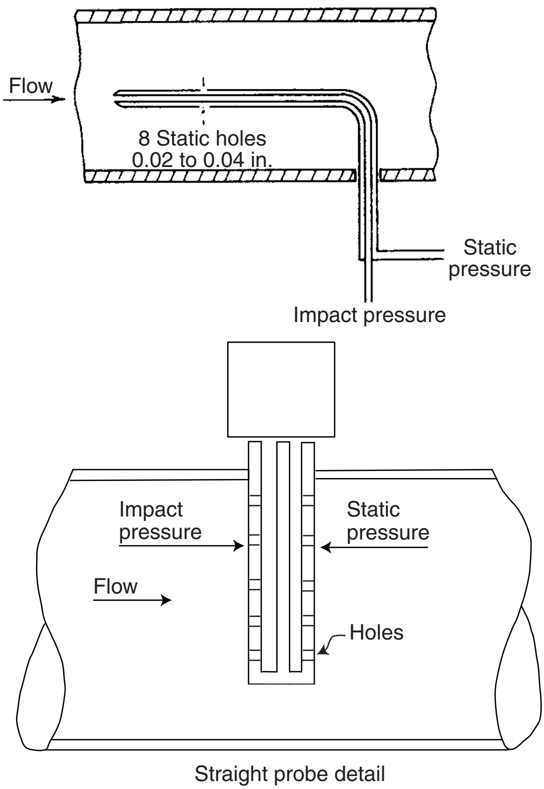


FIGURE 22.9 Pitot tube probe.

where Q = volumetric flow rate, cfs
K = flow coefficient, obtained from probe manufacturer
A = area of pipe, sq ft
G = gravity constant (32 ft/sec/sec)
DP = differential pressure, psi
D = liquid density, lbs per cu. ft

Elbow Taps

An elbow tap is a differential-pressure-measurement-type meter that measures flow rate. It has no moving parts. This method of measuring flow rate uses the difference in pressure exerted by the centrifugal force of the flowing liquid around the outside walls or inside and outside walls of a 90 degree elbow that forms a regular part of the piping distribution system. A typical elbow tap arrangement is illustrated in Fig. 22.10.

Pressure measurements are obtained by placing taps at the center (45°) position on both the inside and outside wall or on the outside wall only of the elbow. The differences in pressure can be measured by a pressure sensing instrument package and converted into flow rate.

Flow is calculated by the following formula:

$$W = 244 \sqrt{r\, h\, D^3\, p} \tag{22.6}$$

where W = flow rate, lbs per hour
r = elbow radius, inches
h = differential pressure, inches water column
D = elbow diameter, inches
p = density of fluid being measured, lbs per ft

Flow Nozzle

A flow nozzle is a differential-pressure-type meter that measures flow rate. It has no moving parts. It is similar to an orifice meter except it has a flow nozzle instead of an orifice plate with a large tapered throat. This enables the flow nozzle meter to measure liquids with moderate suspended solids and has the same pressure drop with 60 percent higher flow rates than orifice plates. A typical flow-nozzle-type meter is illustrated in Fig. 22.11.

The basic operation requires a primary and secondary element. The primary element, or flow nozzle, constricts the flow of liquid. This produces a difference in

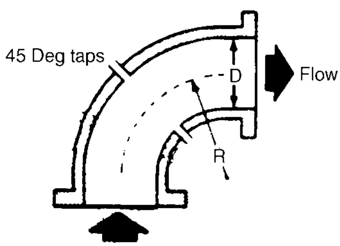


FIGURE 22.10 Typical elbow tap.

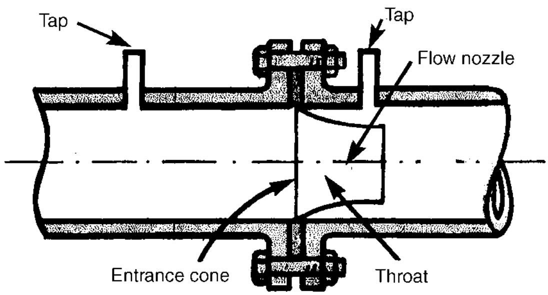


FIGURE 22.11 Typical flow nozzle.

pressure on both sides of the nozzle. The secondary element measures the differential pressure and provides the signal or readout that is converted to the actual flowrate value. The instrumentation package that is used to measure the different pressures and provide the readout is installed into taps on both sides of the nozzle.

The flow nozzle will measure approximately 60 percent greater flow with the same pressure drop through the meter as an orifice meter.

Flow is calculated by using eq. 22.2, the same as that for orifice meters.

Rotary Vane

The rotary vane meter is a positive displacement meter and is available in several designs. The basic unit consists of an equally divided rotating impeller that contains two or more compartments mounted inside the meter's housing. The impeller is in continuous contact with the casing. A fixed volume of liquid is swept into the meter's outlet from each compartment as the impeller rotates. The revolutions of the impeller are counted and registered as volumetric units.

Helix Flowmeter

The helix flowmeter is a positive-displacement-type meter that uses helical rotors geared together to displace liquid axially from one end of the chamber to the other.

Disk Meter

The disk meter, with variations of the basic design known as a notating disk and oscillating piston meter, is a positive-displacement-type meter. Many sizes and capacities are available, and the units can be made from a wide selection of materials.

The notating meter mechanism consists of a movable disk mounted on a concentric sphere located in a spherical, side walled chamber. The pressure of the liquid passing through the measuring chamber causes the disk to rock in a circular path without rotating on its own axis. The disk is the only moving part in the measuring chamber. A typical disk meter is illustrated in Fig. 22.12.

A pin extending perpendicularly from the disk is connected to a mechanical counter that monitors the disk's rocking motion. Each cycle is proportional to a specific quantity of flow.

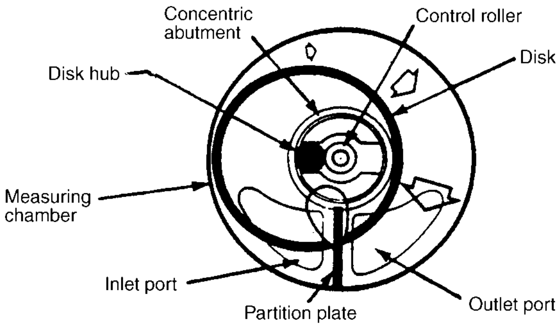


FIGURE 22.12 Typical disk meter.

The oscillating piston meter operates by means of a magnetic drive, so that the liquid does not come in contact with the meter body.

Turbine Meters

The turbine meter (often called a current meter) is a velocity-type meter that uses a multiple bladed rotor (similar to a propeller on a boat) mounted in the flow stream perpendicular to the liquid flow. The rotor has blades (vanes) that rotate as the fluid passes through the vanes. The speed of the rotor is a direct function of the flow rate and can be counted in a number of ways. It can also be used to determine volume. A typical turbine meter is illustrated in Fig. 22.13.

A variation of the turbine meter is called a paddlewheel meter, which uses a multiple flat bladed rotor installed parallel to the liquid flow that rotates in the flow stream. The rotation speed varies with velocity of the fluid.

The device can be used in both open channels and closed piping.

Vortex Flowmeters

A vortex meter, also known as a vortex shedding meter, is a velocity-type meter with no moving parts. It makes use of a natural phenomenon that occurs when a liquid flows around an element, known as a bluff body, that is suspended in the flow stream. Eddies, or vortices, are created (shed) and flow downstream of the bluff body. The frequency of the vortex shedding is directly proportional to the velocity of the liquid flowing through the meter. Its use for slurries or high viscosity liquids is not recommended. A vortex meter is illustrated in Fig. 22.14.

The three components of a vortex meter are the bluff body strut mounted in the flow stream, a sensor to detect the presence of vortices and to generate an electrical impulse, and a signal amplification package, the output of which is proportional to the flow rate. Straightening vanes may be required.

Swirl Meter

A swirl meter is a velocity-type meter that is a variation of the vortex meter. The basic operating principle is similar, except that the fluid entering the meter is forced

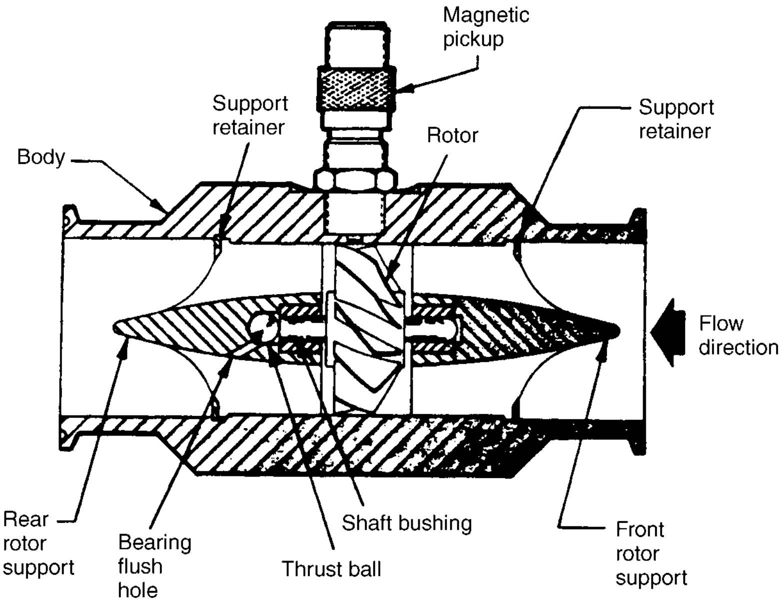


FIGURE 22.13 Typical turbine meter.

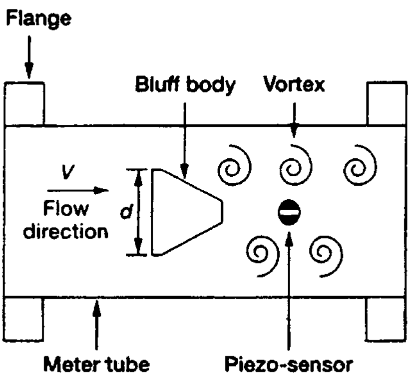


FIGURE 22.14 Typical vortex meter.

into a continuous swirl pattern instead of periodically producing vortices. Due to the meter geometry, straight run pipe requirements upstream of the meter are minimal. A typical swirlmeter is illustrated in Fig. 22.15

The swirl pattern is then conducted into a helical path, turning the swirl pattern on its side, similar to that of a tornado being converted into a screw type thread pattern. This creates a precession-like motion that is linear in proportion to the flow rate. The frequency of the precession is detected by a sensor and instrument package and converted into flow rate.

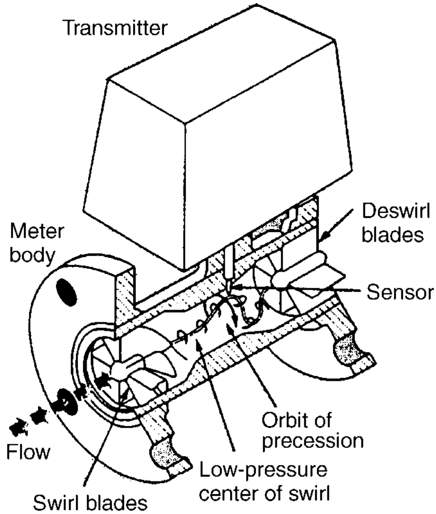


FIGURE 22.15 Typical swirlmeter.

Target Meter

The target meter is a volumetric-type meter. It senses and measures forces caused by a flowing liquid that impact on a drag disk, or target, suspended in the flow stream. A typical target meter is illustrated in Fig. 22.16.

This meter can measure liquids, gases, steam and slurries and is most useful in metering dirty or corrosive liquids. Accuracy is generally between ½ and 1 percent full flow. It has a wide range of flow rates, and the disk can be optimized to suit any range of application. There is a pressure loss due to the suspended target. A use for a simple target meter is to determine if a fluid is moving at all, or if it is moving slowly or with high velocity with no requirement for quantity.

The target is typically a circular disk mounted on a hinged swinging shaft installed concentrically in the pipe perpendicular to the direction of flow. It is supported on a circular shaft that extends from the target through a shaft seal to a force-measuring secondary element, usually a strain gauge, and instrument package. Volumetric flowrate is inferred from fluid velocity and the known open area of the meter.

Oval Gear Flowmeter

The oval gear meter is a displacement type meter. The basic operating principle is the use of oval shaped gear toothed rotors that rotate in a chamber of specially designed geometry. As the rotors turn, they sweep out and trap very precise amounts of liquid with none of the liquid passing through the rotors. As the rotors turn, each rotation is a measured amount of fluid and is counted by an instrument package. The pulsation of flow is minimal. It operates best when there is little backpressure.

This meter is well suited to measure higher viscosity liquids such as lubricating oil, diesel fuel, and syrups, but a higher pressure is required to operate the meter

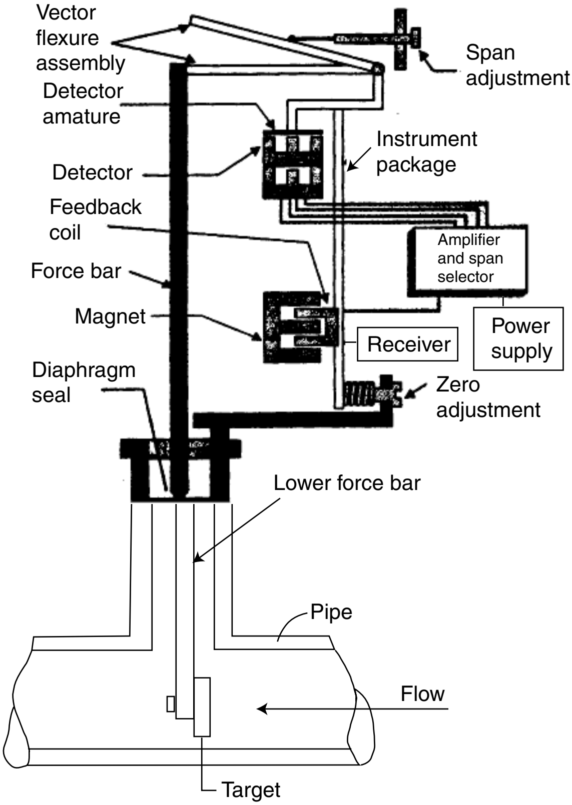


FIGURE 22.16 Typical target meter.

the higher the viscosity. No straight runs are required for accuracy. It is not recommended for water because of slippage between gears and is unsuitable for gases.

ELECTRONIC (ELECTROMAGNETIC) FLOWMETERS

Electronic meters are divided into two general categories: magnetic and Doppler.

Magnetic Flowmeters

A magnetic flowmeter is essentially a single package with wire coils mounted on or outside a suitably insulated piece of pipe (flowtube) and the electronics necessary for flow measurement. It operates on Faraday's Law of electromagnetic induction where a voltage will be induced when a conductor (fluid) moves through a magnetic field. It has no moving parts or obstructions to flow, so the pressure drop through the meter is equivalent to a straight piece of pipe. It is well suited to measure corrosive fluids and slurries and is unaffected by changes in temperature, pressure, fluid density or viscosity. It is not suited for measurement for non-conductive liquids such as hydrocarbons. To function correctly the pipe must be full. The wetted transducer mounting is preferred if the fluid is low density, such as a gas. The clamp-on is preferred for liquids. A hybrid device is also available to combine the advantages of both types. The operation of a typical magnetic flowmeter is illustrated in Fig 22.17.

The magnetic flowmeter consists of three primary components: the flowtube, the flow transmitter, and an instrument package that measures the induced voltage and converts the voltage readings to flowrates.

These meters measure the flowrate of any electrically conductive liquid using Faraday's Law of electromagnetic induction. Faraday's Law is expressed as:

$$E = B \times V \times D \tag{22.7}$$

where E = generated voltage
B = magnetic flux density
V = fluid velocity
D = pipe diameter or distance between electrodes

Since B and D are constant, E is then proportional to V.

Ultrasonic Flowmeters

Ultrasonic meters consist of two main types: Doppler and transit time. The Doppler flowmeter is a velocity type flowmeter. An ultrasound beam is generated at a common frequency of 500 kHz at an oblique angle to the flow. The flowmeters use what is technically called the contrapropagation method of ultrasonic flow measurement, which is sound pulse reflection rates. Ultrasound is generated by means

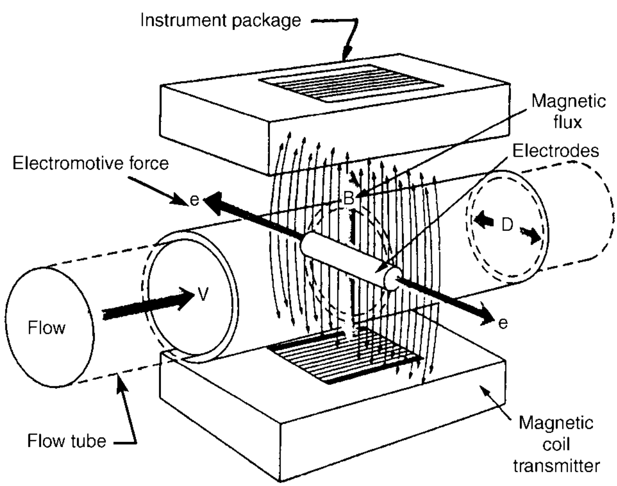


FIGURE 22.17 Typical magnetic flowmeter.

of piezoelectric transducers installed either inside the pipe (wetted) or outside (clamp-on). Transit times are measured in the direction of flow, and later (or sometimes simultaneously) against the direction of flow. From the two measured transit times of the beams, the velocity can be calculated.

The generated beam is reflected from suspended particles or bubbles in the fluid stream being measured. The reflected beam shifts frequency and mixes with the original transmitted frequency. This reflected and transmitted beam is then collected and measured by an instrument package (receiving transducer) that converts the frequency shift into fluid flow rate. A simplified illustration of Doppler operation is given in Fig. 22. 18.

Doppler flowmeters are not generally used for clean fluids. It is most useful for any liquid containing suspended droplets such as slurries, sludges, emulsions, dispersions and pulps.

Identifying suitable fluids for Doppler meters is a complex combination of four basic criteria. How well these criteria are met determines the suitability and accuracy of using a Doppler flowmeter. These criteria are:

1. The scattering material must have a sonic impedance different from that of the fluid that is being metered.
2. There must be some particles large enough to cause longitudinal scattering.
3. For any given pipe size the longitudinal scattering must have sufficient energy to overcome the energy wasted (Rayleigh scattering) that is caused by smaller particles.
4. The scattering velocity must travel at the same velocity as the fluid for good accuracy.

The Transit Time Flowmeter

The transit time flowmeter is a velocity type flowmeter and is a variation of the Doppler flowmeter. The difference is that the fluid must be relatively free of entrained gas or solids to minimize or eliminate signal scattering or absorption.

The meter operates by having ultrasound signal transducers mounted on each side of the pipe. This configuration is such that the ultrasound waves traveling between the transducers are at a 45 degree angle to the direction of liquid flow. A time differential relationship proportional to the flow can be obtained by transmit-

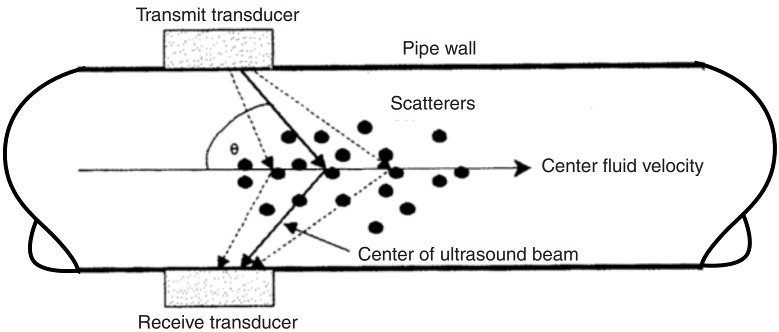


FIGURE 22.18 Simplified Doppler flowmeter operation.

ting the signal alternately in both directions. When flow begins in either direction, the pulse traveling in the same direction as flow reaches its destination faster than the pulse traveling in the opposite direction. The difference in transit time across the pipe is proportional to the flow velocity.

FLOWMETER SELECTION

There are some primary factors that should be considered prior to the selection of any particular method of flow metering. Table 22.1 is an inclusive list, all of which may not apply of any specific installation. It is intended for review in order to provide a checklist.

Table 22.2 is intended to present a general selection guide giving primary characteristics of the flowmeters discussed. Consult the manufacturers for a complete technical discussion of parameters not mentioned and for any unusual conditions.

To convert fluid velocity into flowrate, use the following formula:

$$\text{GPM} = \frac{\text{ID}^2 \text{ (in feet)} \times \text{velocity (fps)}}{0.408} \tag{22.8}$$

TABLE 22.1 Factors Influencing Flowmeter Choice

Performance factors	Viscosity
Accuracy	Lubricity
Repeatability	Chemical properties
Linearity	Surface tension
Rangeability (turndown)	Compressibility
Pressure drop	Abrasiveness
Output signal characteristics	Pressure or other phrases
Response time	Presence of other components
Purpose of measurement	**Environmental factors**
Suspended particles	Ambient temperature effects
Installation factors	Humidity effects
Available space	Safety factors
Flow direction	Pressure effects
Upstream and downstream pipe work	Electrical interference
Line size	**Economic factors**
Location for servicing	Purchase price
Effects of local vibration	Installation costs
Location of valves	Operation costs
Electrical connections	Maintenance costs
Provision of accessories	Calibration costs
Hazardous atmosphere	Meter life
Effect of pulsations/unsteady flow	Spares cost and availability
Ease of installation	Pumping power and head loss
Fluid property factors	Technical optimization
Liquid or gas	
Temperature and pressure	
Density	
Specific gravity	

TABLE 22.2 Flowmeter Selection Guide

Flowmeter element	Recommended service	Turndown (rangeability)[1]	Pressure loss	Typical accuracy, percent	Required upstream pipe, diameters	Viscosity effect	Relative cost
Orifice	Clean, dirty liquids; some slurries	4 to 1	Medium	±2 to ±4 of full scale[2]	10 to 30	High	Low
Venturi tube	Clean, dirty, and viscous liquids; some slurries	4 to 1	Low	±1 of full scale	5 to 20	High	Medium
Flow nozzle	Clean, and dirty liquids	4 to 1	Medium	±1 to ±2 of full scale	10 to 30	High	Medium
Pitot tube	Clean liquid	3 to 1	Very low	±3 to ±5 of full scale	20 to 30	Low	Low
Elbow meter	Clean, dirty liquids; some slurries	3 to 1	Very low	±5 to ±10 of full scale	30	Low	Low
Target meter	Clean, dirty, viscous liquids; some slurries	10 to 1	Medium	±1 to ±5 of full scale	10 to 30	Medium	Medium
Variable meter	Clean, dirty, viscous liquids	10 to 1	Medium	±1 to ±10 of full scale	None	Medium	Low
Positive displacement	Clean, viscous liquids	10 to 1	High	±5 of rate[3]	None	High	Medium
Turbine	Clean, viscous liquids	20 to 1	High	±0.25 of rate	5 to 10	High	High
Vortex	Clean, dirty liquids	10 to 1	Medium	±1 of rate	10 to 20	Medium	High
Electromagnetic	Clean, dirty viscous conuctive liquids and slurries	40 to 1	None	±0.5 of rate	5	None	High
Doppler	Dirty, viscous liquids and slurries	10 to 1	None	±5 of full scale	5 to 30	None	High
Time-of-travel	Clean, viscous liquids	20 to 1	None	±1 to ±5 of full scale	5 to 30	None	High
Coriolis	Clean, dirty, viscous liquids; some slurries	10 to 1	Low	±0.4 of rate	None	None	High
Thermal	Clean, dirty, viscous liquids; some slurries	10 to 1	Low	±1 of full scale	None	None	High

[1] For given transmitter span setting
[2] Percent of the flowmeter's full range
[3] Percent of liquid flow rate

LEVEL MEASUREMENT

GENERAL

This subsection will discuss the measuring of liquid levels (product) in atmospheric and pressurized tanks to allow an operator to The evolution of level measurement has advanced from the manual methods of using a stick or rope that exposed an operator to potentially hazardous conditions to multiple technologies that are very accurate and repeatable.

There are two general categories of level measurement devices: continuous system and point measurement. The continuous system indicates the level of product in a vessel over a specified range of measurement. It is the most flexible because the sensing element is fixed and any number of control points can be adjusted at will. It can also be provided with a method for recording the levels for inventory management or to establish demand. In general, the point measurement indicates if product is present at those points, or not. The point method is less costly and can be more accurate at control points. Control points can be provided to indicate high level, low level, pump control and spill prevention.

LEVEL TECHNOLOGIES

Codes and Standards

Some of the federal regulations regarding fugitive emissions and spills for level technologies are summarized in Table 22.3.

Float-based Devices

Float-based devices are a continuous system and the most basic means of measuring liquid level. It uses a float that remains on top of the liquid level in an atmospheric vessel. The position of the float or floats are coupled to switches that indicate the level at any point. The float can be coupled to a switch by mechanical, magnetic or a cable suspension link. A multiple point float is illustrated in Fig. 22.19a and a single point float in Fig. 22.19b.

The float switches can also be used to start and stop pumps and to perform alarm functions with the proper electronics and alarm signals.

Radio Frequency Admittance and Capacitance

A capacitance level gauge and the radio frequency admittance gauge are similar technologies. Both are continuous and point measuring systems depending on the instrument package. The two capacitance concepts of measurement both employ the same technology with enhancements for the different types. The basic system

TABLE 22.3 Regulations Covering Fugitive Emissions and Spills

Hazardous Organic National Emisson Standard for Hazardous Air Pollutants (NESHAP) [HON]	Requires regular monitoring of process connections, such as flanges, fittings, valves, etc., for fugitive emissions in processes containing hazardous volatile organic compounds (VOCs)
Spill Prevention Control and Countermeasure (SPCC) Regulation	Requires registering of tanks, reporting of spills, and submission of a downstream notification plan (for which overfill protection is critical)
Oil Pollution Prevention Act of 1990	Requires companies that transfer oil over navigable waters or areas with runoff accessible to navigable waters to have a plan to respond to "worst case scenarios"
Superfund Amendments and Reauthorization Act (SARA) Title III (also known as the Emergency Planning and Community Right-to-Know Act)	Requires companies to file annual reports detailing spills, leaks, emissions, and other releases of hazardous materials, as well as activities designed to reduce releases, such as overfill protection, automatic shutoffvalves, new procedures, etc.
American Petroleum Institute (API) Recommended Practice 2350	Recommends a high level alarm independent of any gauging system for spill prevention; a test on the spill prevention system should simulate an actual high level condition but should not require filling the vessel above its normal fill level
National Fire Protection Association (NFPA) NFPA 30, Section 10, Preventing Overfilling of Tanks	Requires spill prevention for flammable and combustible liquids; requirements include frequent visual observations by plant personnel, high level devices with audible alarms independent of tank gauging equipment, and the ability to test these systems

operates by means of a long cylindrical probe immersed in a conductive product that contains no moving parts.

The radio frequency admittance probe is two plates of a capacitor supplied with a radio frequency (rf) signal, with the dielectric between the two plates being the product. As the impedance between the plates changes with a change in liquid level, an instrument package converts the changing signal into liquid level. An rf admittance gauge is illustrated in Fig. 22.20. This gauge can handle a wide range of temperature and pressure differences.

The plain capacitance level gauge is similar except that there is no rf generator but rather a capacitance measurement instrument. The capacitance at the probe is measured and sent to an instrument package for conversion into level indication.

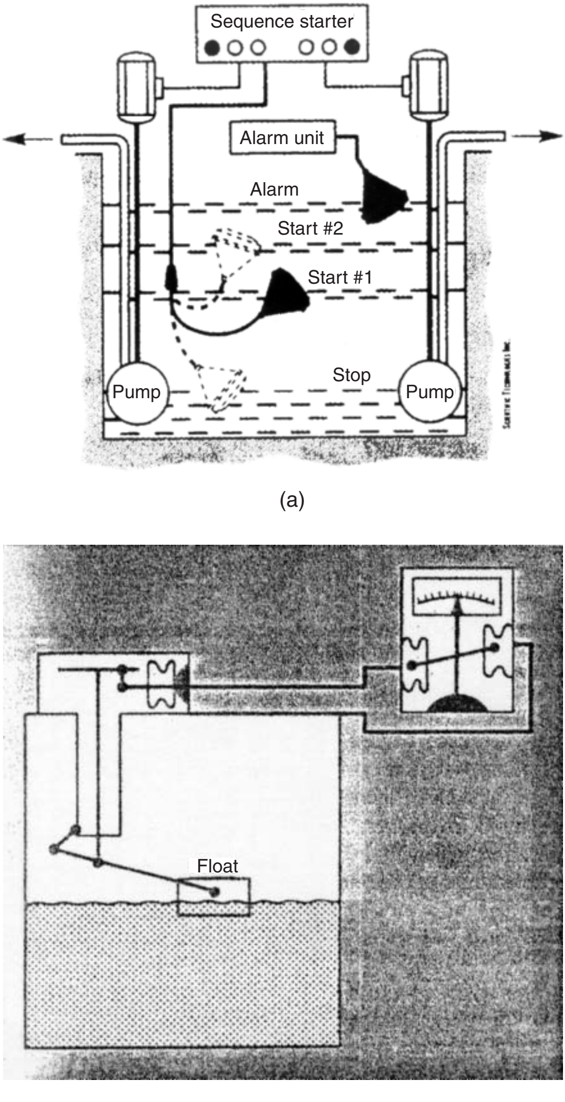


FIGURE 22.19 (*a*) Multiple point float. (*b*) Single point float.

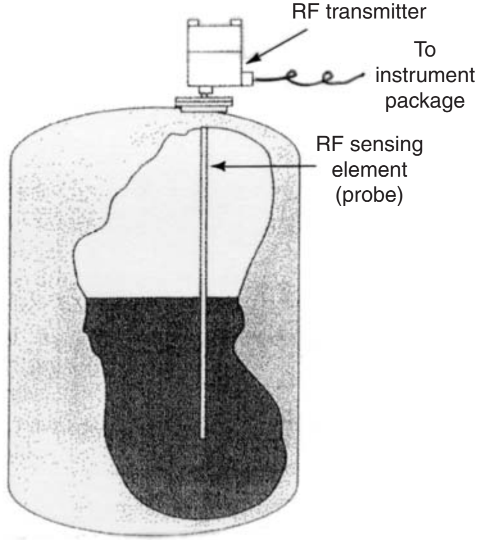


FIGURE 22.20 RF admittance gauge.

For non-conductive product, the vessel wall or an auxiliary reference plate provides the other capacitor reference plate. A capacitance level gauge is illustrated in Fig. 22.21. Wide ranging temperature and pressure differences do have an effect on the installation.

These systems require only one penetration into the vessel and are effective with high temperature liquids and pressures up to 3,000 psig (20,700 kPa). They also have an advantage in hazardous environments. They are suitable for slurries and

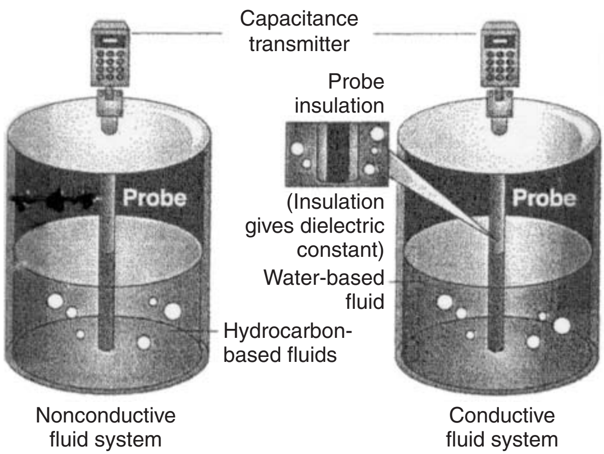


FIGURE 22.21 Capacitance gage.

where there may be above average turbulence. Another advantage is the probe can be set up to measure the level of different interface levels of products with different impedances.

Disadvantages are that the probe is sensitive to different product dielectric properties. Also, changes to vapor space content above the product also effect output so that the instrument package must be readjusted.

Pressure Gauge

Level measurements by pressure gauges can be accomplished by means of either single pressure or differential pressure (DP) measurements. This type of gauge is the most popular method of tank measurement. It works by means of measuring the pressure from product in a tank or vessel applied to a sensing element and transmitter (sensor) installed outside the tank in a housing directly connected at the bottom of the product tank. It does not measure the level directly, but only the head (height) or pressure exerted by the product. The head multiplied by the product density yields the level measurement. To measure levels in an open or vented tank, a single sensor/pressure transmitter is used. When installed in a pressurized tank, a second sensor/pressure transmitter is necessary to provide a differential pressure referenced to the pressure above the liquid level. This is illustrated in Fig. 22.22.

DP works best with clean liquids. Product that may coat the sensor is not recommended because of maintenance problems.

Bubblers

Bubblers operate on the principle of forcing air through a tube immersed in the liquid. The basic system consists of air pipe immersed in the product to the bottom, a regulated air supply, and differential pressure transmitter. As air bubbles escape from the open bottom of the tube, the air pressure in the tube corresponds to the hydraulic head inside the tank and varies with any change in level. Air is introduced

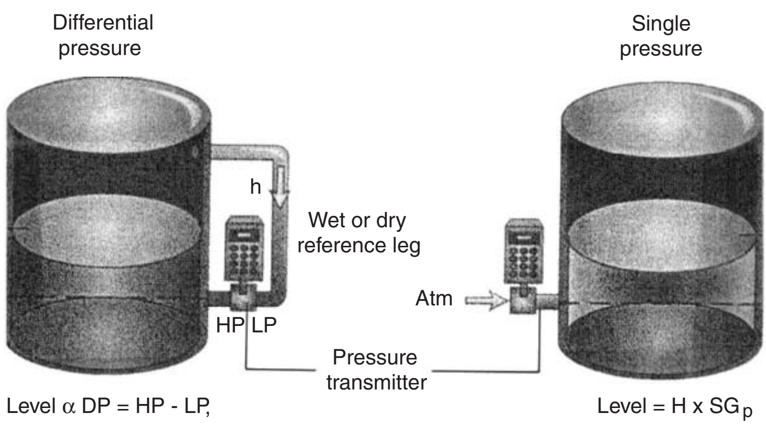


FIGURE 22.22 Pressure gauges.

into the system from a facility air supply that is regulated. An instrument package measures the back pressure of that air, and an instrument package converts the changing signal into liquid level. A typical bubbler system is illustrated in Fig. 22.23.

Accuracy is about 10 percent of full scale and depends on a stable and regulated air supply. This is less precise that many other systems.

Bubbler systems are relatively simple and inexpensive, easy to install and can be placed inside a full tank. In general, they are limited to atmospheric tanks. They are well suited for underground tank installations.

Disadvantages include difficulty in calibration and inaccuracies due to changing product density. Product with suspended solids has a tendency to clog the tube.

Ultrasonic Systems

Ultrasonic devices operate by having a transmitter produce a continuous high frequency, ultrasonic sound pulse. The pulse is directed toward the liquid level surface where it is reflected back as an echo. The time lapse for the echo to return and be received by a transducer is converted by an instrument package into a measured level of liquid. This system is capable of both continuous or point measurements. A typical ultrasound installation is illustrated in Fig. 22.24.

Ultrasound is non-invasive, contains no moving parts and measurement is unaffected by changes in density, pH and dielectric properties of the liquid. It is suitable for liquids and slurries. Acceptable temperature for installation is limited to about 300°F (152°C) and pressure to 50 psig (340 kPa). Only one penetration is necessary, and the penetration is above the level of product. The transmitter and transducer do not come into contact with product. It is not susceptible to fouling where petroleum products or other hazardous material is present.

It should not be considered for high temperature, stratified vapor, steam, excessive foam, as turbulence and dust may cause the signal to be distorted.

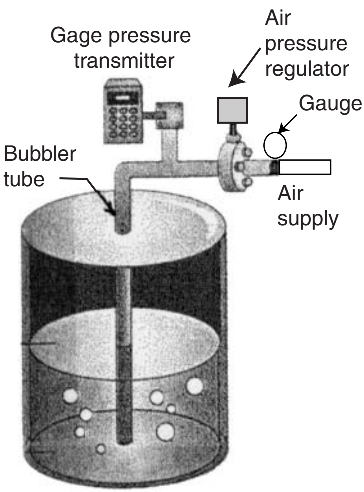


FIGURE 22.23 Bubbler level system.

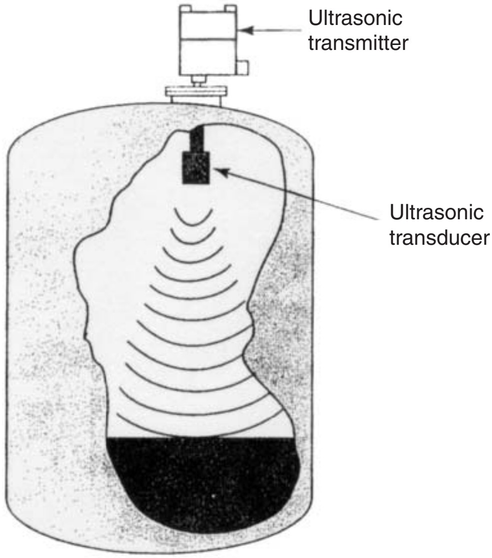


FIGURE 22.24 Ultrasonic measurement.

Radar Systems

Radar is similar to the ultrasonic systems. It produces and transmits high-frequency electromagnetic waves to the surface of the liquid and reflects the waves back to a receiver. The return time is proportional to the level of the liquid.

Radar is non-invasive, contains no moving parts and measurement is unaffected by changes in density, pH and dielectric properties of the liquid. It is suitable for liquids and slurries. It is not affected by any interference caused by any gas in the vapor space. Turbulence presents no problems for the signal.

Radar cannot measure interface levels.

Nuclear Measurement

Nuclear devices use the absorption or attenuation of gamma rays released from radioisotopes as they pass through the tank and product from one side to the other. Gamma radiation is a high energy, short wavelength energy, similar to that of x-rays, that have great penetrating power. Different isotopes are used based on the amount of penetration required to pass through the tank and product. A gamma ray source is mounted externally on one side of the tank and a sensitive detector is placed externally on the other. The strength of the signal indicates the level of the liquid. The percentage of gamma transmission decreases as the level increases. A typical nuclear measurement system is illustrated in Fig. 22.25.

Nuclear is non-invasive and can be used as a point, continuous or interface indicator. It is not affected by hazardous and corrosive material and is considered more reliable than electronic methods. Measurements are totally unaffected by temperature, pressure, or product corrosiveness. Readings may be influenced by

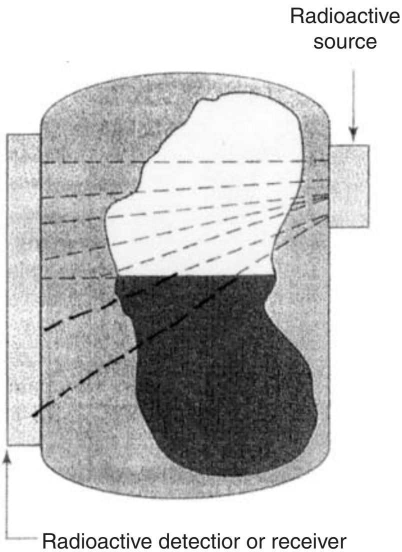


FIGURE 22.25 Nuclear measurement system.

changes in product specific gravity. Nuclear technology is often used when other types of measurement fail.

Nuclear measurement has a high initial cost, often two to four times that of other methods. Spent radiation sources are difficult and expensive to replace and dispose of. Licenses, permits, approvals and inspections are required during the useful life of the system. The system requires continuous monitoring and produces discomfort for the maintenance personnel that is difficult to determine.

Displacement System

A displacement system is most often a continuous measurement system. It uses a sealed, heavy body immersed in the product, as compared to floats that are intended to stay on the liquid's surface. It is based on Archimedes' principle that a submerged body is buoyed up by a force equal to that of the weight of liquid being displaced. Displacement forces are expressed as:

$$F = V \times D \tag{22.9}$$

where F = displacement force
V = volume of submerged body
D = density of fluid

The operating principle of a submerged system is buoyancy, where the buoyant force of the liquid to be measured is exerted on a sealed body (displacer). As the fluid rises in the vessel, the displacer weight is buoyed up in proportion to the rise in liquid level. This weight difference is measured and converted to level measurement by an instrument package. This is illustrated in Fig. 22.26. There are several variations in use, including the use of a displacing chamber installed on the outside of the vessel similar to that of a sight glass.

The displacement system is primarily used in pressurized or closed tanks to measure slurries, liquid-vapor interfaces and liquid-liquid differences where the liquids have different specific gravities. Installed in a stilling well, it is suitable for turbulent situations.

It is not recommended where product could deposit material on the displacer. This can be overcome with coatings.

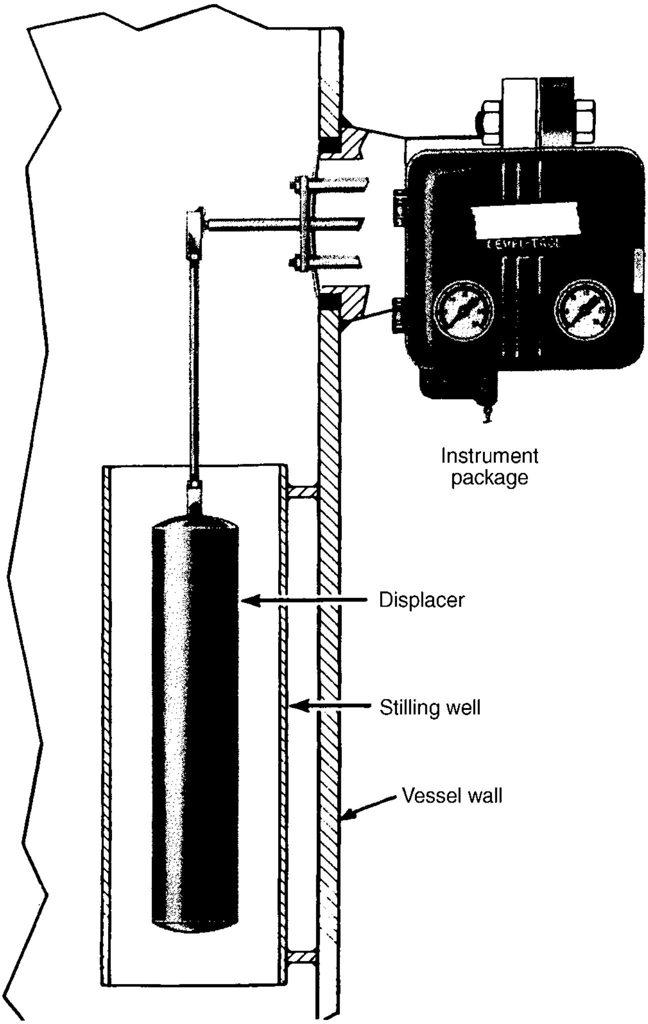


FIGURE 22.26 Displacement system.

Magnetostrictive Liquid Level Measurement

The magnetostrictive level theory is based on the principle of magnetostriction, which is the ability of some metals to expand or contract in the presence of a magnetic field. When a wire, (the magnetostrictive ''waveguide'') is installed inside a guidetube that is surrounded by an axial magnetic field becomes electromagnetized, it twists. It is this amount of twisting that allows a measure of the level to take place. This is illustrated in Fig. 22.27.

The system consists of a wire inside a guidetube, a float (or floats) and a permanent magnet attached to the float. The float is free to move up and down with the level of product in a tank. When an electrical interrogation pulse is sent down

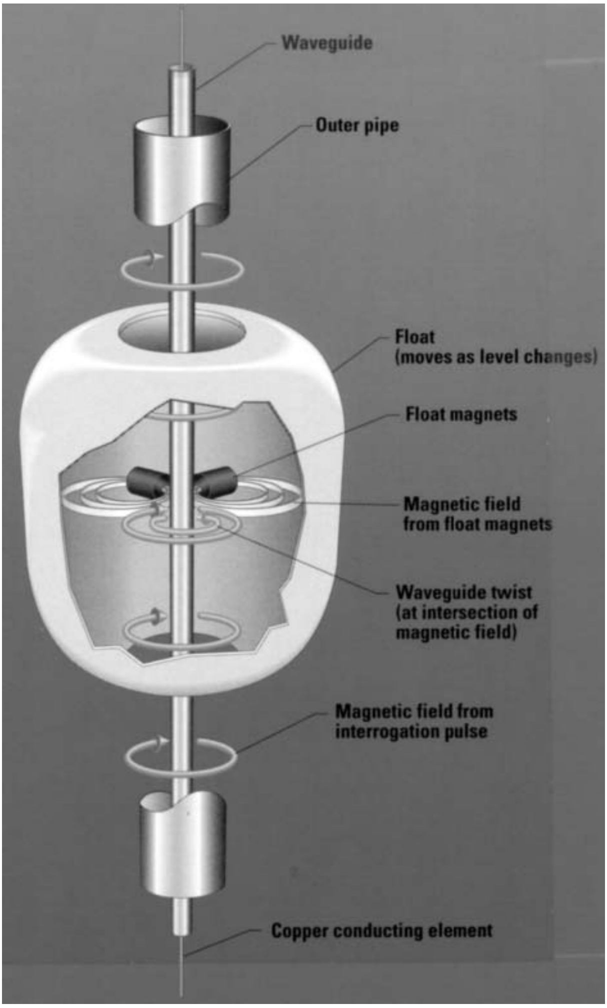


FIGURE 22.27 Magnetostrictive level device.

the wire, this pulse reaches the magnetic field produced by the magnet in the float and produces a twist in the wire. When the pulse travels back to a pickup device, the time of travel is converted by an instrument package into a level measurement.

The main advantage of this system is extreme accuracy. For this reason it is used mostly in liquid fuel tanks to measure product levels. Multiple floats can be installed where there are two liquids of different specific gravity to give separate indications for each, such as water in an oil tank. It has a wide temperature range, a low sensitivity to temperature changes and is not sensitive to pressure, product conductivity, foam, vapor and other atmospheric conditions.

LEVEL MEASUREMENT SELECTION

Table 22.4 is intended to present a general selection guide giving primary characteristics of the level measurement systems discussed. Consult the manufacturers for complete technical details of parameters not mentioned and for any unusual conditions.

TABLE 22.4 Selection Guide for Level-measurement Technologies

Technology	Advantages	Disadvantages	Successful applications	Problem applications
Pressure, D/Ps, bubblers	• Familiarity • Reasonable cost • Simple design • Easy to install	• Affected by density changes • Multiple fugitive-emission points	• Clean liqids with stable densities • Some light slurry use	• Heavy slurry • Coating-buildup applications
Displacer	• Limited motion • Few moving parts	• Affected by density changes • Most require bottom of tank penetration	• Clean liquids with stable densities • Some light slurry use • Interface use	• Small density changes • interfaces • Coating buildup
Float	• Unlimited tank height • Can achieve high accuracy • Low cost if not remote reading	• Moving parts exposed to process • Limited pressure rating • High maintenance	• Most liquids • Light slurries	• Heavy slurries • Granular solids • Interfaces
Ultrasonic	• High accuracy • Non-contacting • Easy calibration	• Position sensitive • Limited temperature and pressure ratings	• Total level of liquids, slurries, some granular solids	• Interfaces measurements • Vapors can cause calibration shifts • Heavy agitation • Vacuum service
RF Capacitance	• Good accuracy • No moving parts • Suitable for wide pressures, temperature range	• Contact measurement • If material properties change, calibration can be affected	• Most liquids • Most slurries • Most liquid-liquid interface measurements • Some granular solids	• Stratified liquids • Granular solids with wide moisture changes
Microwave	• Relatively low cost • Ignores vapors, dusts, and most process variables	• Contact measurement • Not suitable for light powders or some liquefied gases	• Most granular solids • Most liquids • Most slurries • Some stratefied liquids	• Low-dielectric-constant materials, • Corrosive materials • High temperature • High pressure
Radar	• Non-contacting • Suitable for vacuum and pressure service • Ignores vapors and dusts	• Complicated setup • FCC license required by some • Can have high cost • Position sensitive	• Most liquids • Most slurries • Some granular solids	• Low-dielectric-contant materials, (granular solids, liquids) • Heavy agitation • Process that tend to leave heavy coating deposits
Nuclear	• Non-invasive • Reliable • Ignores hazardous and corrosive service	• High cost • License, permits & approval required • Disposal costly	• Corrosive & hazardous materials	• Interface measurement

TEMPERATURE MEASUREMENT

Temperature is defined as the energy level of matter, which is evidenced by some change in that matter. There is a wide variety of temperature sensors and they have one thing in common: they all measure temperature by sensing some change in a physical characteristic of the matter being measured.

The seven most often used types of measurement devices will be discussed.

LIQUID EXPANSION THERMOMETERS

Thermometers are well known liquid expansion devices. In general, they come in two basic classifications: mercury and organic. They operate on the principle that the liquid material in the unit takes on the temperature of the fluid being measured and expands proportionally to the amount of heat sensed by the unit. They are independent of a power supply.

The mercury filled devices have limitations due to environmental concerns. For example, breakage can be hazardous. Therefore, shipping and transportation should be carefully controlled.

Another type of liquid expansion device has a bulb filled with liquid that is connected by a capillary tube to a Bourdon tube. The bulb is immersed in the fluid to be measured. When the liquid expands and contracts, the pressure on the Bourdon tube causes the indicator linkage to rotate and indicate the temperature.

BIMETALLIC DEVICES

These devices operate on the principle of expansion of metals when they are heated. When two metals are bonded together and then heated, one metal expands more than the other causing the bonded metals to rotate. When mechanically linked to a pointer, the rotation will indicate temperature.

They are independent of a power supply and easily portable. They are not as accurate as electrical sensors, and the recording of temperatures is not possible.

CHANGE OF STATE SENSORS

The change-of-state sensors indicate that a change of temperature has occurred. The change of state of these devices cause the device to change color or disappear. Some are capable of reversing color. Commercially available devices include labels, pellets, crayons and lacquers. These devices are slow in response and accuracy is not high.

Labels are used on steam traps that need adjustment. A dot on the label changes color indicating a preselected temperature. This dot color is irreversible for less costly indicators. They are also valuable when conformation is needed that the temperature did not exceed a predetermined temperature.

Liquid crystal devices are available that do reverse color. Some liquid crystal models will have the ability to show different colors for different temperature ranges. Crayons used as an indicator of temperature simply disappear after indication. Pellets become visually deformed.

Although not perfectly precise, these sensors have an advantage when a small, rugged, non-electrical indicator is necessary.

SILICON DIODE

This sensor is a linear device most often used in cryogenic service. It operates on the principle that causes the conductivity to change in direct proportion with a change in product temperature. This change is measured to indicate temperature.

INFRARED SENSORS

An infrared sensor is the only non-contact temperature measuring device discussed. Infrared radiation is emitted from an object corresponding to the temperature. The radiation is received by a sensor (detector) that converts the signal into temperature indications by using a visual screen that converts temperature into color. The color corresponds to temperature.

There are two detectors used: thermal and photon type. The thermal detectors convert incoming radiation into heat, raising the temperature of the thermal detector. The change in temperature is converted to an electrical signal, which is displayed and amplified. Photon detectors react to the photons emitted by the object that cause changes to the electrical properties of the detector unit. These changes are monitored as an output signal.

Infrared units in facilities-type operations are not used for point measurements but rather for maintenance purposes to detect heat emissions from objects where heat is lost due to problems.

THERMOCOUPLES

Thermocouples are electrical devices that measure temperature by measuring a change in voltage. As the temperature goes up, the output voltage of the thermocouple rises. The output voltage is not linear. The National Institute of Standards has established criteria for thermocouples to insure that users can count on reliability and repeatability for many classes of thermocouples.

Thermocouples are basically two dissimilar metals (sensing elements) joined together at a sensing junction. The sensing element is specifically designed to have a specific temperature resistance at a specific temperature. As the temperature increases at the sensing junction, the thermocouple generates an electromotive force proportional to the heat applied. An instrument package converts this signal into temperature measurements. For each thermocouple type, the properties of the metals used dictate the upper range of temperature capable of being sensed.

Thermocouples are generally easy to handle and low cost. They can be installed in rugged environments. When selecting the type, temperature range, sensitivity, accuracy and reliability are important factors to consider.

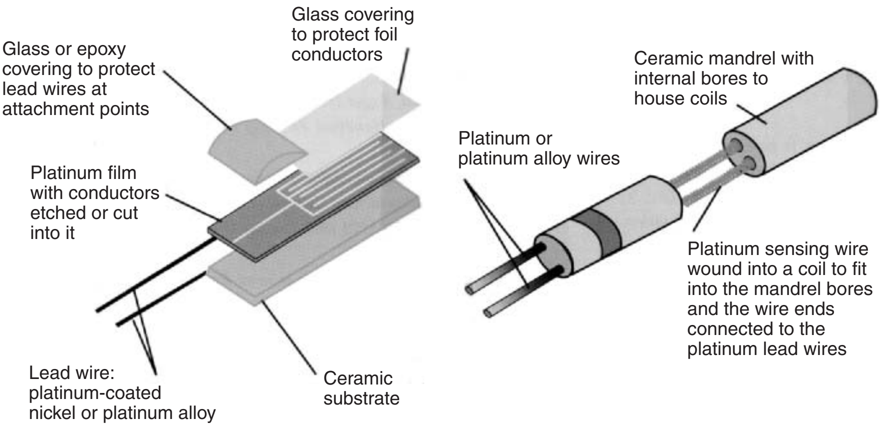


FIGURE 22.28 Typical thermocouples.

TABLE 22.5 Sensing Elements and Temperature Limits

Material	Usable temperature range
Platinum	−450 to 1,200°F
Nickel	−150 to 600°F
Copper	−100 to 300°F
Nickel/Iron	32 to 400°F

RESISTIVE TEMPERATURE DEVICES

Resistive temperature devices (RTD) are electrical devices. Rather than using a change in the voltage as the thermocouple does, this device measures a change in resistance resulting from a change in temperature. This change in voltage is sensed by an instrument package and converted to temperature readings. The two most often used arrangements of RTDs are the wire wound and the film element. These are illustrated in Fig 22.28.

The materials used to construct the RTD have limits that impact their use. The temperature limits of these materials are given in Table 22.5. Another consideration to check when selecting RTDs is the output over the applicable temperature range.

PRESSURE AND VACUUM MEASUREMENT

Pressure and measurements to be discussed will be only for gases and liquids. Vacuum measurements will be only for gases. For a gas, the molecular structure does not have a lattice type of arrangement, and the cohesive forces that bind the molecules together are not as strong as those for a solid. This means that the molecules are quite mobile, and will take the shape of their container. The actual solid volume that the gas atomic structure occupies in relation to the total volume of a gas molecule is quite small, and so, gases are mostly empty space. This is why gases can be compressed. Pressure is produced when molecules of a gas in an enclosed space rapidly strike the enclosing surfaces. If this gas is confined into a smaller and smaller volume, molecules strike the container walls more frequently, producing a greater pressure.

With water, the molecules are quite mobile and also will conform to the shape of the container. However, the molecular structure of water is such that it is practically incompressible. Therefore, added pressure from any source will exert pressure on all parts of a closed system open to the added pressure.

The same gauges discussed can be used for both positive and negative pressures.

MANOMETER

A manometer measures relative pressure between the system and local barometric pressure. It consists of a cylindrical ''U'' tube partially filled with liquid. One end is connected to the system being measured and the other end could be open or closed. The difference between liquid levels in each tube is used to calculate the pressure.

It finds greatest use in determination of leakage rather than being used to measure either pressure or actual flow.

BOURDON GAUGE

An often used type of mechanical gauge is the Bourdon gauge. This type of gauge measures pressure by the amount of deflection that an oval tube bent in an arc and closed at one end exerts under internal pressure. This mechanical gauge is simple, inexpensive and rugged, and is the most widely used type of pressure gauge.

The heart of the gauge is the Bourdon tube that is closed at one end and open to either pressure or vacuum at the other. As the pressure varies, the tube changes shape. A pointer attached to the tube moves, indicating the pressure on a dial. A Bourdon gauge is illustrated in Fig 22.29. The face of the gauge can be filled with oil to dampen pointer vibration.

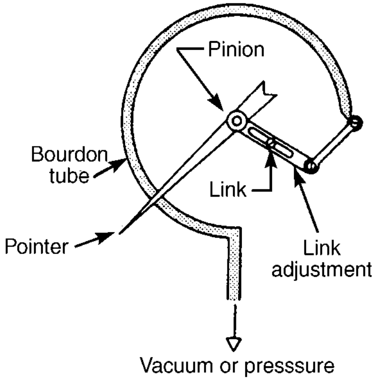


FIGURE 22.29 Bourdon tube gauge.

A Bourdon gauge should not be exposed to temperatures above 150°F (68°C) unless special material is specified.

DIAPHRAGM GAUGES

The diaphragm gauge measures the pressure difference by sensing the deflection of a thin metal diaphragm or capsular element. Similar to the Bourden gauge, its operation relies on the deformation of an elastic metal under pressure that is connected by means of a linkage to a pointer.

Diaphragm gauges are limited to low pressure applications, generally to a limit of 10 psig (70 kPa) full scale.

CAPACITANCE METERS

Capacitance meters are, in essence, electronic diaphragm gauges. Instead of a mechanical linkage, they use a change in a variable capacitance sensor to detect changes in pressure, which is transmitted electronically. The response time is fast and the signal can be remotely transmitted.

STRAIN GAUGES

Strain gauges also use the deflection of a diaphragm to produce a change in electrical resistance of the attached strain gauge. The response time is fast and the signal can be remotely transmitted. A typical strain gauge is illustrated in Fig. 22.30.

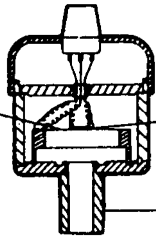


FIGURE 22.30 Strain gauge.

PH MEASUREMENT

pH measures the level of acidity or alkalinity of a solution. The method most used for measurement of liquid in a liquid flow stream is an immersed sensor. The selection of the proper sensor for this purpose is based on accuracy and sensor performance.

A pH sensor consists of a galvanic cell with two electrodes—one that is sensitive to hydrogen ion activity (pH sensor) and a second reference sensor. These electrodes can be either separate or combined into a single probe. The single probe is most often used for facility systems in the measurement of acid waste prior to and after the neutralizing process. A single pH probe is illustrated in Fig. 22.31.

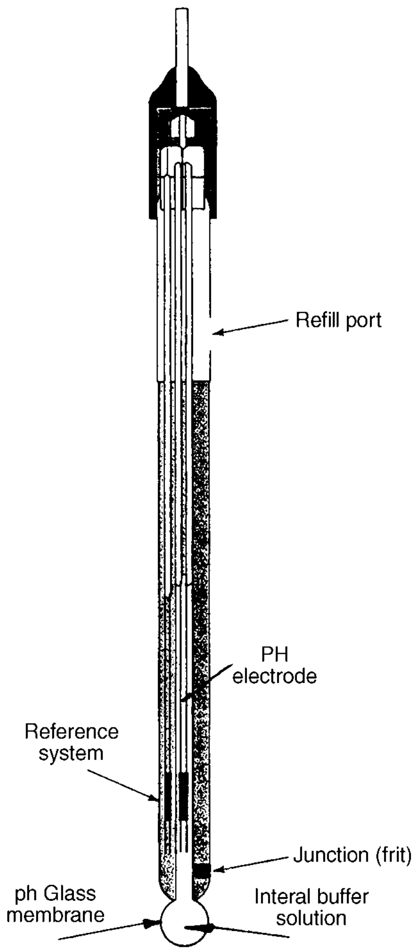


FIGURE 22.31 Single pH probe.

The pH sensitive electrode (or system) is enclosed in a special glass membrane that is sensitive to changes in pH. Such an electrode consists of a metal wire conductor suspended inside a specially constructed glass tube filled with an electrolyte (or buffered) solution. The sensing area in the tip is most often sphere-shaped to provide the largest area for liquid contact and is a membrane especially formulated from pH sensitive material. The fluid being measured permeates the tip and a potential is created between the fluid and the buffered solution.

The reference electrode is constructed of a non-conducting glass envelope containing a reference element. The reference electrode is also filled with an electrolyte. The junction (also called a frit) provides entrance for the liquid being measured. The junctions are made from a variety of non-conductive materials.

The electrodes change electrical potential when immersed in the solution being measured. An instrument package measures this change and converts it into a pH reading or sends a signal to a remote location. The life expectancy of a pH sensor depends on the temperature of the liquid it is immersed in. The higher the temperature, the lower the life. It is recommended that the velocity in the pipe be kept below 9 ft per second to reduce wear.

METERING PUMPS

INTRODUCTION

A metering pump is used to inject a constant, accurate and adjustable flow rate of a liquid chemical additive into a larger process. The primary objective of a metering pump is to effect a predictable and adjustable flow rate that remains stable even when system pressure conditions change.

The most commonly used category of metering pump is a positive displacement pump, which will be the only pump type discussed. What differentiates a metering pump from most positive displacement pumps is its accuracy, which is typically ± 1.0 percent. There are several metering pump types; the most often used are diaphragm, piston, peristaltic and gear pumps. They all have one feature in common, and this is a fixed volume cavity to deliver the same volume with each pumping cycle. The primary challenges of pump design are to control cavity dimensions, minimize leaks and eliminate dead volumes.

METERING PUMP DECRIPTION

Diaphragm Pump

This pump operates by means of a flexible disk, called a diaphragm, that moves back and forth in response to a reciprocating plunger connected to a drive shaft. The discharge is pulsating. A schematic detail showing operation of the diaphragm pump is illustrated in Fig. 22.32.

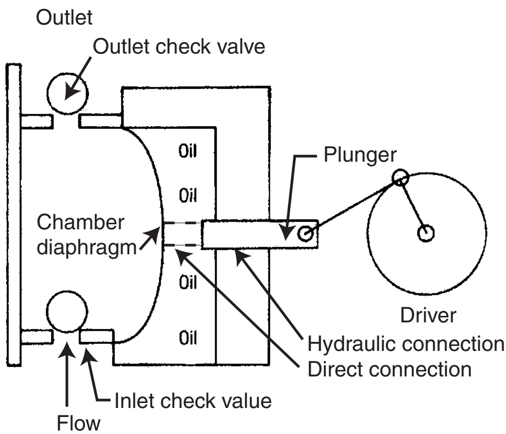


FIGURE 22.32 Typical diaphragm pump.

The operation of the diaphragm pump centers around the pump chamber. One side of the chamber is the pump body and the other side is a flexible diaphragm. A vacuum created by one half of the plunger stroke enlarging the chamber area creates a vacuum that allows the liquid to be pumped to enter the larger chamber. On the other half of the plunger stroke the area of the chamber is compressed, forcing the liquid out of the discharge port. Inlet and outlet check valves are required to prevent short circuiting through the pump. Chemicals to be pumped contact only one side of the diaphragm, which can be lined with a material compatible to the chemical.

The diaphragm pump is available in two configurations of plunger diaphragm connections. One method is to have the plunger directly connected, which creates stress on the diaphragm at the point of attachment. This is less costly but results in a shorter pump life cycle. Since the driver action is fixed, adjustment is made by means of an adjustable stop on the return travel mechanism.

The other method has the space between the plunger and diaphragm filled with hydraulic oil. This is commonly called a hydraulic diaphragm pump. As the plunger moves, it displaces the oil, and this moves the diaphragm. The amount of chemical product pumped is equal to the amount of displaced oil. Flow rate is adjusted by means of a bypass port connected to a reservoir that is adjustable to release oil from the space, thus reducing the amount of oil that is displaced.

The solenoid pump is another method of driving the diaphragm. It operates from a timing mechanism that energizes an electromagnet that slides the plunger into the discharge position. When the magnet is de-energized, it drives the magnet back into the suction position. A system of check valves keeps the fluid flowing in only one direction.

Diaphragm pumps are designed to produce a discharge pressure of approximately 150 psig (1,050 kPa). Pulsation can be reduced by using a pulsation damper installed on the discharge piping of the pump.

Piston Pump

The piston pump operates by means of a reciprocating plunger moving inside a machined cylindrical cavity. The plunger is called a piston and the cavity is called the cylinder. A driver is connected to the piston by eccentric cam. The discharge from the pump is pulsating. A schematic detail showing operation of a gear pump is illustrated in Fig. 22.33.

The power train and driver provides the rotary motion that drives the piston in and out inside the cylinder. The connection from the driver to the piston is eccentric to convert the rotary motion to a straight reciprocal action. As the piston is driven rearward, the volume in the chamber is increased and a suction is created that draws liquid chemical into the chamber. An inlet check valve allows the fluid to flow only one way—inside the chamber. The piston direction is then reversed, decreasing the chamber volume and increasing the pressure on the fluid causing it to discharge. The outlet check valve now opens, allowing the fluid to flow out of the discharge line.

The flow rate can be regulated either by varying the speed of the driver or by making an adjustment to the piston stroke length to vary the displacement of the piston in the cylinder.

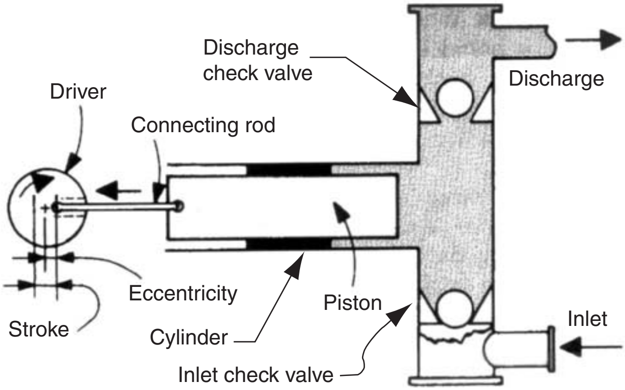


FIGURE 22.33 Typical piston pump.

Peristaltic Pump

This pump operates by means of a revolving roller compressing a smooth wall, flexible tube with fluid inside the tube. As the roller rotates, the fluid is forced through the tube from inlet to outlet. A schematic detail showing operation of a peristaltic pump is illustrated in Fig. 22.34.

The operating principle is to have the tube squeezed and released by a roller along a predetermined length positively displacing the fluid inside. The tube recovers its shape after the squeezing action that produces a vacuum drawing more chemical into the tube. This provides a gentle pumping action that causes little damage to the chemical being pumped. The volume of chemical discharged per cycle is proportional to the tube diameter and the distance between rollers. The amount of fluid between the rollers is called the ''pillow volume.''

There are several advantages to this pump. With the chemical being pumped totally enclosed in the flexible tubing, no path for leakage or fugitive emissions is

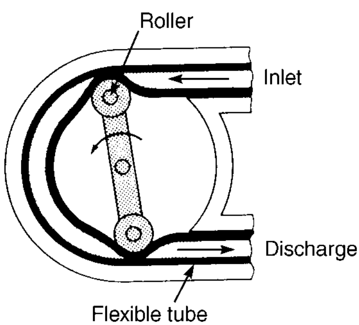


FIGURE 22.34 Typical peristaltic pump.

provided. The hose can easily be removed from the pump body for cleaning. The tube can be easily changed for different chemicals.

The discharge is pulsed, but this can be reduced by using multiple rollers to produce an almost steady flow. The key to selection of the pump is to optimize the tube material for compatibility with the chemical being pumped, the tube diameter and distance between rollers to match the flow rate required. Pump head is determined by the characteristics of the tube selected, which is typically 50 psig (340 kPa). The pump volume can be adjusted only by varying the rotation speed.

Gear Pump

A gear pump operates by means of a pair of continuously rotating elements with gear teeth. The design of the teeth create a cavity that when filled with liquid and rotated moves liquid through the pump. Flow is determined by the amount of fluid in the teeth multiplied by the number of teeth and the rotation speed. A gear pump is illustrated in Fig 22.35.

The operating principle is to have fluid introduced into the inlet and find its way between the gears of the rotating element. It is then carried around the pump between the teeth of the gears and the centrifugal action gives the fluid its added pressure. No check valves are required because of the very close tolerances of the tips of the gear teeth inside the pump body retaining the liquid. Because of the number of teeth on the rotating element, the flow is virtually continuous. Flow rate is adjusted by varying the rotating speed of the driver.

These pumps are well suited for liquids of wide range of viscosity. Other advantages include non-pulsating flow, simple piping arrangement, low first cost, and less tendency to leak. The major disadvantage is that the gear pump has a decreasing output when pumping against an increasing backpressure.

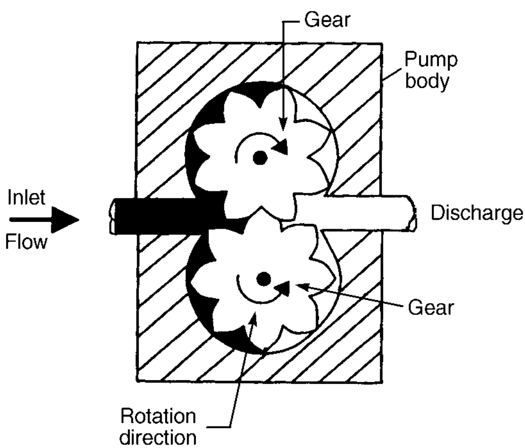


FIGURE 22.35 Typical gear pump.

METERING PUMP CONSIDERATIONS

The following considerations and ancillary devices may be required for systems to avoid problems. Not all of the devices will be necessary for all installations. A typical metering pump system for a larger scale chemical injection is illustrated in Fig 22.36.

Controlling Flow Rate

There are two primary methods used to control the flow rate: an adjustable speed motor and adjustment of the pump's displacement or stroke. If the pump is to be operated in the top 50 percent of its range, either method can be used. Experience has shown that the variable speed method is more accurate if the pump is to be operated in the lower portion of the range.

Backpressure Valve

A backpressure valve is another name for a check valve. It is installed on the outlet of a metering pump to assure that flow occurs in only one direction. Metering pumps may also require that the pressure at the discharge of the pump be greater than the pressure at the inlet of the pump. There are two reasons for this. First, if sufficient discharge pressure is not present, liquid could flow freely through the pump; second, flow rate accuracy is lost.

A similar check valve is required on the inlet side of the pump.

Pulsation Dampeners

A pulsation dampener smooths out the pulsations from a pump, and in doing so the pressure and force exerted on the piping is reduced as well as water hammer. If a flowmeter is used, the indications will be more accurate. The following is considered good engineering practice for installation of a pulsation dampener.

1. Locate the pulsation dampener near the discharge of the pump. The reason is that the pulsation dampener only dampens the pulses downstream of itself. It does not dampen flow between itself and the pump.
2. Install a pressure gauge downstream of the pulsation dampener.
3. Do not reduce the pipe size between the pump and the pulsation dampener.
4. Precharge the dampener with dry nitrogen to a pressure of 80 to 85 percent of the lowest normal operating pressure. The pressure rating of the dampener shall equal system pressure and temperature.
5. Select the size of the pulsation dampener to equal to approximately 15 pump strokes.

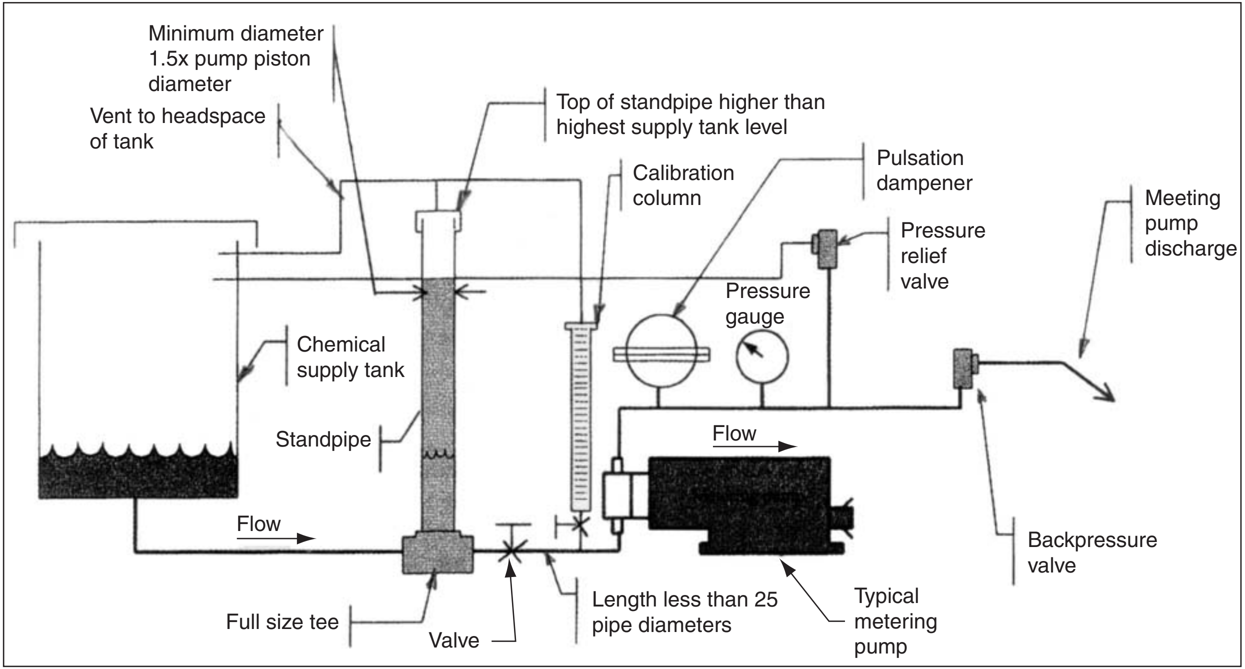


FIGURE 22.36 Typical metering system.

Suction Pipe Size

The suction pipe size probably has the most effect on successful pump operation. Generally accepted practice sizes the suction pipe at one size larger than the pump inlet connection. To actually size the inlet where there may be a problem, an NPSH analysis should be performed, understanding that the peak flow rate from each stroke will be at least three times the average flow rate.

Discharge Pipe Size

If a pulsation dampener is used, it is common practice to size the discharge piping ½ to ¾ the size of the pump outlet size. If no pulsation dampener is used, the discharge shall be sized at least as large, if not one size larger. Acceleration pressure drop is another consideration.

Standpipe

A standpipe, which is nothing more than a straight length of pipe, will eliminate flow pulsations between the pump and chemical supply, will eliminate acceleration pressure drop and reduce the frictional pressure drop by a factor of three. It should be capped and vented back to the supply or a separate tank. It should be installed in a full size tee and extend higher than the highest level of the chemical supply tank.

Calibration Column

A calibration column is used to measure the pump flow rate. It is essentially a small length of glass pipe with calibration marks. It is used by filling the column with chemical and cutting off the supply from the main source. When the mump is started, the exact amount of chemical delivered can be observed.

FLOW IN OPEN CHANNELS

Open channel flow is the flow of liquids in a channel the geometry of which has one liquid surface free of solid boundaries. A channel is often called a conduit. This section will discuss flow measurement techniques for open channels other than in pipes. Gravity, non-pressurized flow in pipes can be found in Chap. 6, Storm Water System.

The flow in open channels, or conduits, is classified into two types: steady and unsteady flow. Steady flow is a constant rate of discharge, and unsteady flow is characterized as variable rate of discharge over time. A flow is uniform if velocity and depth are constant along the conduit. If velocity and depth change in the conduit, the flow is unsteady.

CALCULATING THE HYDRAULIC RADIUS OF AN OPEN CHANNEL

Often the hydraulic radius of the conduit must be found in order to calculate the flow rate. This is accomplished by first calculating the area of the water flowing in the channel in square feet. Next, determine the contact surface of the flowing water contacting the bottom and sides of the channel, in feet. To calculate the hydraulic radius, divide the area by the length of contact surface. The answer is in feet.

CALCULATING THE FLOW OF AN OPEN CHANNEL

A widely used method used to find the flow in open channels is the Manning formula. This is very similar to, and yields the same results as, Kutter's formula.

Fig. 22.37, a graphical solution of the Manning formula, has been developed for use in open channels. In order to enter the figure, most of the following must be determined or calculated.

1. *Hydraulic radius*. Refer to previous discussion.

2. *"n" value* for friction coefficient of the channel. Refer to Table 22.6.

3. *The average velocity* of the flow stream can be found by placing a floating object in the stream and observing the amount of time it takes to move a given distance. Generally accepted practice requires that the surface velocity be reduced by 15 percent to give the average velocity.

4. *Loss of head* can only be determined from other criteria. If the hydraulic radius and average velocity is known, the loss of head per 1,000 feet can be found in Fig. 22.38. This chart is calculated for an "n" value of 0.01, which is an average value.

5. To use the chart, first connect the hydraulic radius point with the head loss point with a straightedge. Where the imaginary line crosses the pivot point, rotate

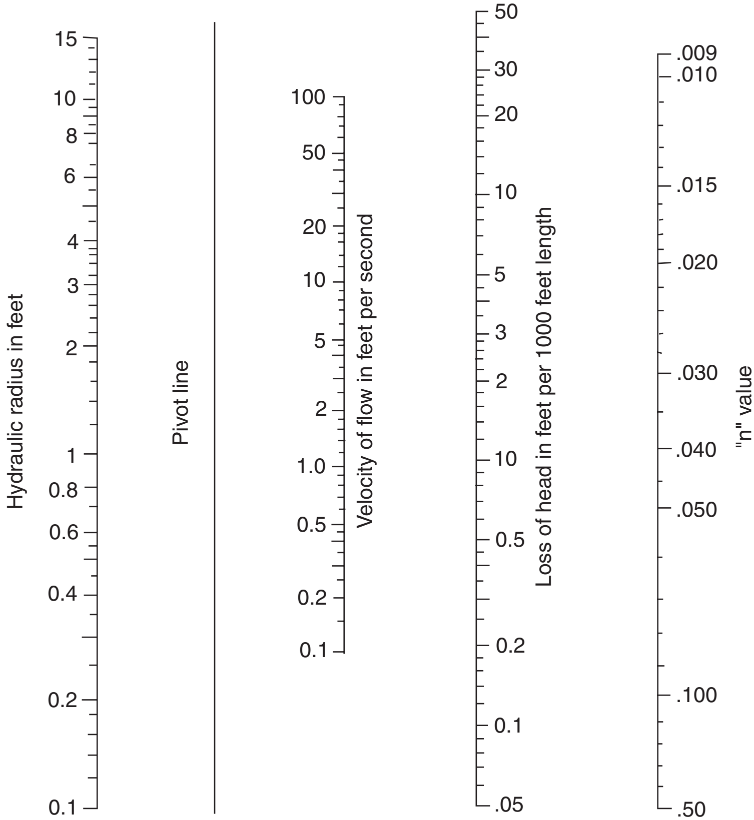


FIGURE 22.37 Graphical solution to Mannings formula.

the straightedge from the pivot point just found to cross the established "n" value on the proper scale. Read the velocity on the velocity scale.

6. Multiply the velocity by the area of the flowing water to find the flow rate in cfs.

METERS FOR MEASURING FLOWRATE IN OPEN CHANNELS

Current Meter

The operating principles of a current meter are similar to those of the previously discussed turbine meter. This type of meter should be considered when the use of a weir is not practical because of insufficient head.

TABLE 22.6 "n" Value for Use in Mannings Formula. For Open Channels.

	Min	Avg	Max
A. Lined channels	0.011	0.012	0.014
1. Metal			
a. Smooth steel (unpainted)			
b. Corrugated	0.021	0.025	0.030
2. Wood			
a. Planed, untreated	0.010	0.012	0.014
3. Concrete			
a. Float, finish	0.013	0.015	0.016
b. Gunite, good section	0.016	0.019	0.023
c. Gunite, wavy section	0.018	0.022	0.025
4. Masonry			
a. Cemented	0.017	0.025	0.030
b. Dry rubble	0.023	0.032	0.035
5. Asphalt			
a. Smooth	0.013	0.013	
b. Rough	0.016	0.016	
B. Unlined channels			
1. Excavated earth, straight and uniform			
a. Clean, after weathering	0.018	0.022	0.025
b. With short grass, few weeds	0.022	0.027	0.033
c. Dense weeds, high as flow depth	0.050	0.080	0.120
d. Dense brush, high stage	0.080	0.100	0.140
2. Dredged earth			
a. No vegetation	0.025	0.028	0.033
b. Light brush on banks	0.035	0.050	0.060
3. Rock cuts			
a. Smooth and uniform	0.025	0.035	0.040
b. Jagged and irregular	0.035	0.040	0.050

Flume

A flume is a specially designed open channel flow section that has engineered restrictions in the area that produces an increase in velocity of the fluid being measured. The most widely used flumes are the *Parchall Flume,* illustrated in Fig. 22.39, and the *Palmer-Bowles* flume.

The flume measures water flow because the design of the flume has the head of water surface in the converging section proportional to the flow through the flume. The increase in height is measured by instrument packages and converted into flow rates.

Flumes generally require relatively smooth flow of approximately 10 diameters upstream for proper operation. They should not be installed near a sharp change of slope or adjacent to obstructions in the flow path. They are selected where low head loss is important and where large amounts of suspended solids may be present.

Weirs

A weir is a dam or obstruction placed in the flow path of a partially filled pipe or channel. Because of the obstruction, water will back up behind the barrier creating

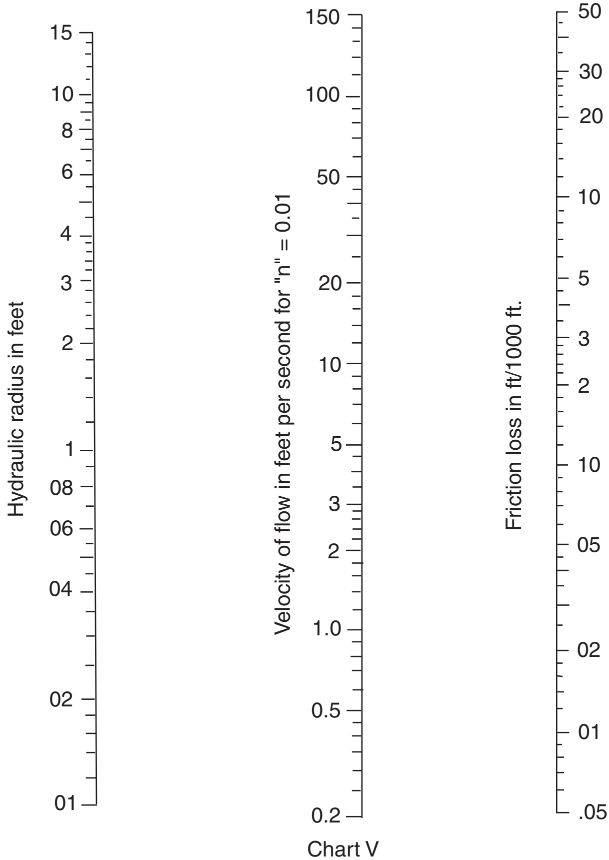


FIGURE 22.38 Chart to find head loss in Mannings formula for open channels.

a head of water. That head is a function of flow velocity, and therefore the flowrate through the weir. There is an opening that allows water to freely flow through the opening. A cross section through a weir is illustrated in Fig. 22.40. This opening has three shapes: rectangular, triangular and Cippolletti. These shapes are illustrated in Fig. 22.41. The difference in geometry between the Cippolletti and rectangular or triangular shape is that the Cippolletti weir has a 4 to 1 slope ratio of the sides. The advantage of the Cippolletti weir is that the discharge occurs as if there is no end contraction and no correction to the flow rate is necessary.

Discharge rates are found by obtaining the measurement of the vertical distance from the weir crest to the surface of the water. In order to assure accuracy, the measurement must be taken some distance upstream of the weir. Generally accepted practice used for measuring the head of water places the staff gauge at distance of at least four times the head of water upstream of the weir crest.

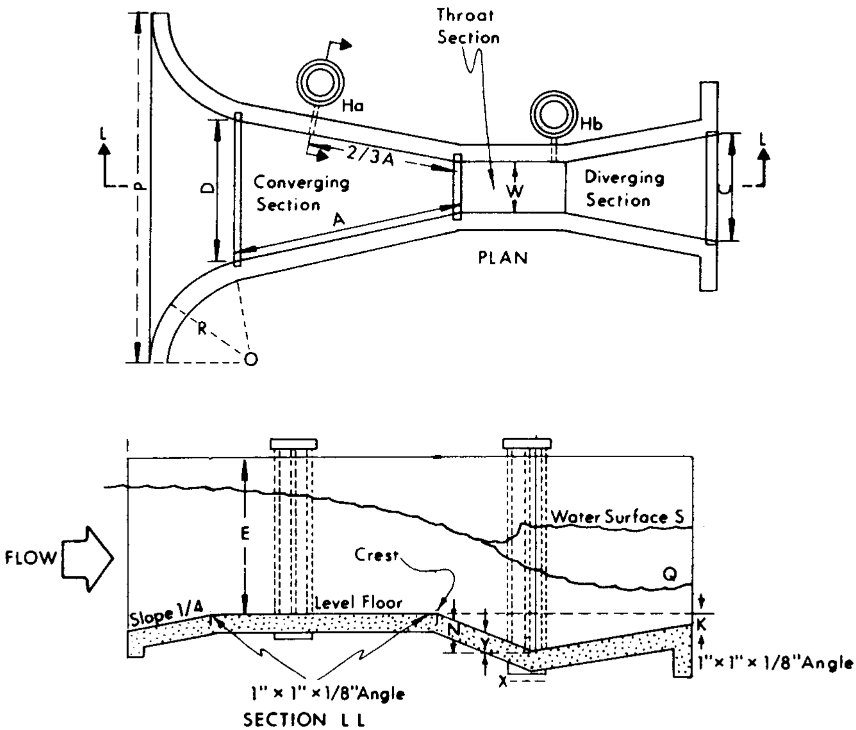


FIGURE 22.39 Plan and sectional views of a Parshall flume.

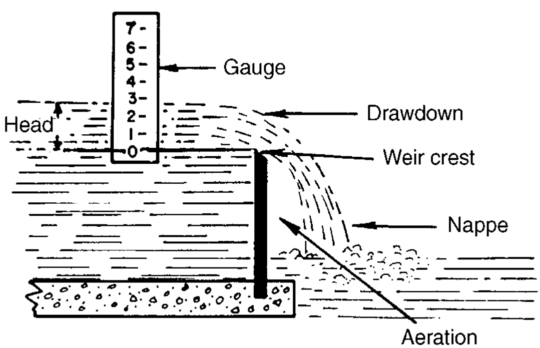


FIGURE 22.40 Cross section through a weir.

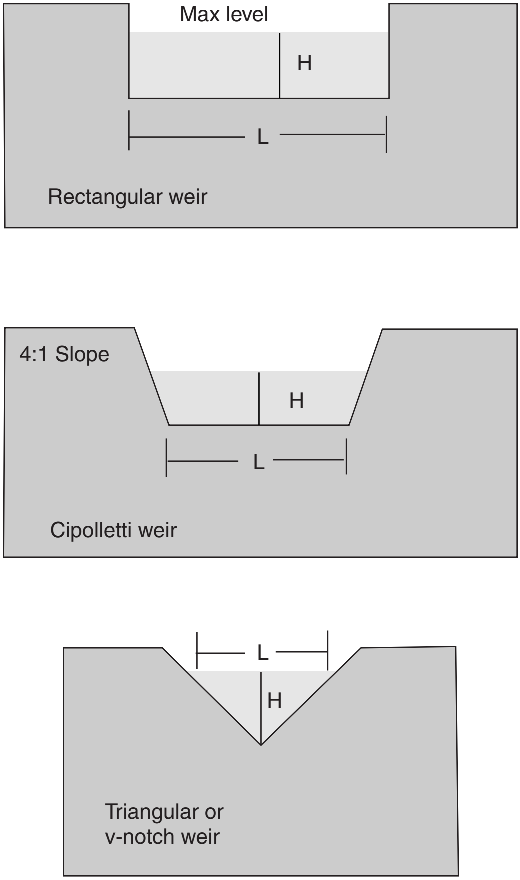


FIGURE 22.41 Types of sharp-crested weirs.

The basic formulas for flow through the various weirs are:

1. For rectangular or square weirs $Q = 3.33 \times L \times H^{3/2}$ (22.10)
2. For Cippolletti weirs $Q = 3.37 \times L \times H^{3/2}$ (22.11)
3. For triangular weirs (90°) $Q = 2.44 \times H^{5/2}$ (22.12)
4. For triangular weirs (60°) $Q = 1.41 \times H^{5/2}$ (22.13)

where Q = flow rate in cfs
L = for rectangular weir, length of weir, ft
For Cippolletti weir, length at base, ft
For triangular weir, length of water at flowing level above notch.
H = measured head, ft

Table 22.7 is a tabular solution for discharge from a rectangular weir. Cippolletti weirs are calculated using Table 22.7 with a length equal to that at the bottom of

TABLE 22.7 Flow-through Rectangular Weirs—GPM

	Length (L) of weir in feet					Length (L) of weir in feet		
Head (H) in inches	1	3	5	Additional gpm for each ft over 5 ft	Head (H) in inches	3	5	Additional gpm for each ft over 5 ft
1	35.4	107.5	179.8	36.05	8	2338	3956	814
1¼	49.5	150.4	250.4	50.4	8¼	2442	4140	850
1½	64.9	197	329.5	66.2	8½	2540	4312	890
1¾	81	248	415	83.5	8¾	2656	4511	929
1	98.5	302	506	102	9	2765	4699	970
2¼	117	361	605	122	9¼	2876	4899	1011
2½	136.2	422	706	143	9½	2985	5098	1051
2¾	157	485	815	165	9¾	3101	5288	1091
3	177.8	552	926	187	10	3216	5490	1136
3¼	199.8	624	1047	211	10½	3480	5940	1230
3½	222	695	1167	236	11	3716	6355	1320
3¾	245	769	1292	261	11½	3960	6780	1420
4	269	846	1424	288	12	4185	7165	1495
4¼	293.6	925	1559	316	12½	4430	7595	1575
4½	318	1006	1696	345	13	4660	8010	1660
4¾	344	1091	1835	374	13½	4950	8510	1780
5	370	1175	1985	405	14	5215	8980	1885
5¼	395.5	1262	2130	434	14½	5475	9440	1985
5½	421.6	1352	2282	465	15	5740	9920	2090
5¾	449	1442	2440	495	15½	6015	10400	2165
6	476.5	1535	2600	528	16	6290	10900	2300
6¼		1632	2760	560	16½	6565	11380	2410
6½		1742	2920	596	17	6925	11970	2520
6¾		1826	3094	630	17½	7140	12410	2640
7		1928	3260	668	18	7410	12900	2745
7¼		2029	3436	701.5	18½	7695	13410	2855
7½		2130	3609	736	19	7980	13940	2970
7¾		2238	3785	774	19½	8280	14460	3090

the weir. Table 22.8 is the tabular solution for discharge from triangular weirs. Interpolation should be used to calculate discharges for intermediate dimensions.

Sluice Gates

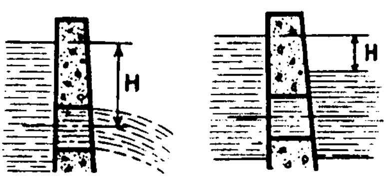
A sluice gate is a device used in controlling the flow in open channels, canals or rivers. It consists of an opening installed in a full obstruction in a channel that is controlled by an operable gate. The gate can be raised or lowered by means of a manual gear-operated drive that opens the gate from the bottom of the channel, allowing water to flow out.

TABLE 22.8 Flow-through Triangular Weirs

Head (H) in inches	Flow in gallons per min 90° notch	Flow in gallons per min 60° notch	Head (H) in inches	Flow in gallons per min 90° notch	Flow in gallons per min 60° notch	Head (H) in inches	Flow in gallons per min 90° notch	Flow in gallons per min 60° notch
1	2.19	1.27	6¾	260	150	15	1912	1104
1¼	3.83	2.21	7	284	164	15½	2073	1197
1½	6.05	3.49	7¼	310	179	16	2246	1297
1¾	8.89	5.13	7½	338	195	16½	2426	1401
2	12.4	7.16	7¾	367	212	17	2614	1509
2¼	16.7	9.62	8	397	229	17½	2810	1623
2½	21.7	12.5	8¼	429	248	18	3016	1741
2¾	27.5	15.9	8½	462	267	18½	3229	1864
3	34.2	19.7	8¾	498	287	19	3452	1993
3¼	41.8	24.1	9	533	308	19½	3684	2127
3½	50.3	29.0	9¼	571	330	20	3924	2266
3¾	59.7	34.5	9½	610	352	20½	4174	2410
4	70.2	40.5	9¾	651	376	21	4433	2560
4¼	81.7	47.2	10	694	401	21½	4702	2715
4½	94.2	54.4	10½	784	452	22	4980	2875
4¾	108	62.3	11	880	508	23½	5268	3041
5	123	70.8	11½	984	568	23	4565	3213
5¼	139	80.0	12	1094	632	23½	5873	3391
5½	156	89.9	12½	1212	700	24	6190	3574
5¾	174	100	13	1337	772	24½	6518	3763
6	193	112	13½	1469	848	25	6855	3958
6¼	214	124	14	1609	929			
6½	236	136	14½	1756	1014			

Free Discharge of Water into the Atmosphere. Use the illustration shown in Fig 22.42a. To find the flow rate of water discharged through a sluice gate, the area of the opening necessary to discharge a given flow rate or head of water above the as, refer to Fig. 22.43, entering the chart with any two values to find the third.

Submerged Discharge of Water. Use the illustration shown in Fig. 22.42b. The solution is similar to that of free discharge except that the head of water used in the calculations is the difference of water levels as shown in the illustration.



(a) (b)

FIGURE 22.42 Sluice gates.

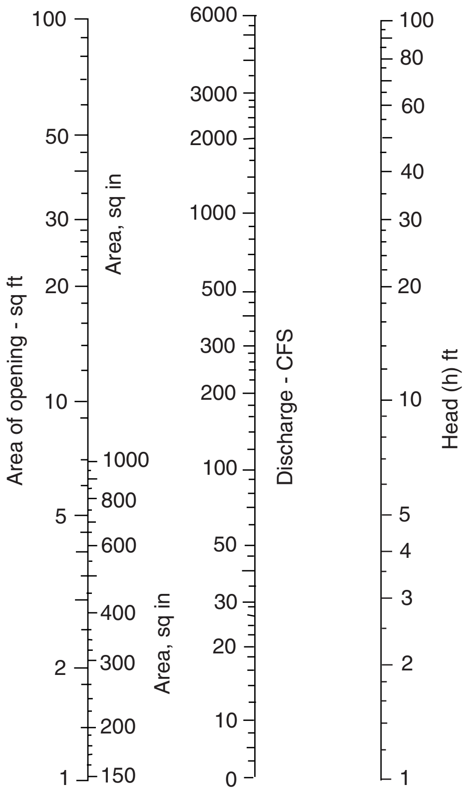


FIGURE 22.43 Sluice gate discharge.

MISCELLANEOUS DEVICES AND MEASUREMENT METHODS

Sight Glass

A sight glass is a "U" shaped transparent device that allows the contents of the vessel to freely move inside it. It is connected to the side of a vessel and measures the level of a liquid inside. A connection is made at the extreme top and bottom of the vessel, and as the level of liquid inside the vessel changes, it changes inside the sight glass. This is the only method that allows direct visual observation of levels and can be the most accurate.

Thermowells

A thermowell is an enclosed attachment to a pipe that permits the insertion of a temperature measuring device. It is important that the thermowell be installed in that portion of the pipe run capable of producing the least measurement error. The most common method of thermowell attachment is by means of a threaded con-

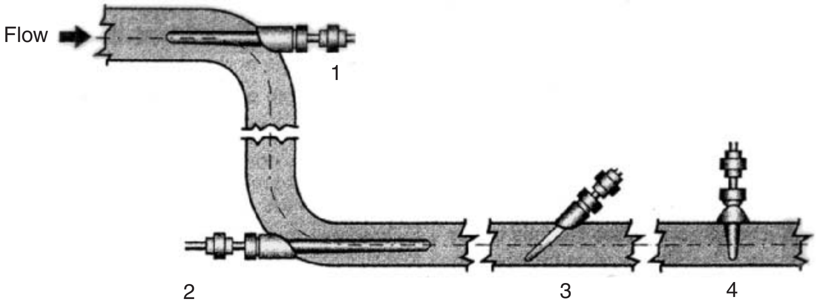


FIGURE 22.44 Preferred thermowell locations.

TABLE 22.9 Angles of Repose

Material	Angle, deg
Anthracite ash	45
Cinders, bit. coal	25–41
Coal, anthracite	27
Coal, bituminous	35
Coke (piled loose)	30–45
Gravel, round	30
Gravel, sharp	40
Clay, soft	10
Clay, compacted	20–25
Sand-clay, compacted	40–50
Sand, dry	25–35
Sand, moist	30–45
Sand, wet	20–40
Silt, compacted	25–40
Silt, loose	20–30
Soda ash, dense	42
Soda ash, light	59
Sulfur, granules	35
Salt	36
Cement	37.5
Iron ore	35–45
Scrap metal	35–45
Plastic resin grains:	
Cellulose acetate	16
Fluorocarbon	6
Nylon	9
Vinyl	10
Viscose	10

nection. The distance the thermometer intrudes into the pipe is called the immersion. For the most accurate measurement, the immersion shall be at least into the center of the pipe.

The location of the thermowell is important. Fig. 22.44 illustrates the four most preferred methods of installing a thermowell in a pipeline.

Space for Piled Materials

When working with volumes of piled materials, one is occasionally faced with calculating the amount of material in a pile or how much a given amount of ground area a piled material will occupy. In order to accomplish this calculation, the angle of repose must be known.

The *angle of repose* is the angle between the naturally occurring sloping surface of the pile and the ground level that a piled material will naturally assume. The angle of repose for common materials is given in Table 22.9. The angle of repose is generally found by observation or laboratory tests and is based on the lowest limit of internal friction of the material.

Knowing the angle of repose and the shape of the pile (conical, wedge, etc.), the area can be calculated using trigonometric functions found in standard engineering texts. With the area and weight of the material known, the actual quantity of the material can be found.

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